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PART II
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PART II : PRESIDENTIAL ADDRESSES

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FORTY-FIFTH INDIAN SCIENCE CONGRESS

MADRAS, 1958

Congress President :—PROF. M. S. THACKER, B.Sc. (Eng.), D.Sc. (Hon.), M.I.E.E. (Lond.), M.I.E. (Ind.), M.Inst.F. (Lond.), M.I.M. (Lond.), M.Ind.-I.M., M.Elec.chem.-s., A.M.I.R.E., F.Am.-I.E.E., F.A.Sc., F.N.I.

PRESIDENTIAL ADDRESS

The convention that the President of the Indian Science Congress should address the annual gathering of scientists, enjoins me to stand before you this afternoon, but while conventionally, the President elects to speak on a specialized field of science or technology, with which he is intimately associated, I propose to make a departure and address you on a subject which is not connected with my expertisé, but which concerns us all and, at the same time, is in conformity with the main objective of the Association, namely, "to advance and promote the cause of science in India". I felt, and I felt strongly, that an opportunity such as this should be utilized for sharing with you my thoughts and musings, my dreams and hopes, on the basic requirements for the advancement of science as a whole. I am convinced that without addressing ourselves to what I may call the 'grammar' of scientific development, our progress can at best be halting and our achievements, of a routine character.

It would be trite to say, today, in plan-conscious India, when the nation's endeavours are canalized to raise productivity and through it, the standard of living of the people, that the advancement of science and technology is a dire necessity. I am not a believer in slogans, but I cannot help giving expression to my conviction that without an abundance of science and technology and without establishing them on a self-perpetuating and exponentially expanding basis, I see little hope of progress. This may sound strong, but the writing on the wall is clear, thanks to the stupendous and far-reaching developments in nuclear fission and fusion and artificial earth satellites. We can ignore science and technology only at our peril.

What are our responsibilities, then, as scientists in the promotion and advancement of the cause of science in India? We have been endeavouring, particularly since Independence, to expand facilities for teaching and research in science and technology, and while we have achieved during one decade much more than in many previous decades, I may be pardoned if I feel impatient and say that we have not done enough. The problems before us are many and the need for solving them is urgent. In the context of the developments which are taking place in other countries, our attempts appear to be feeble. If we have to make progress, the 'climate' for science and technology must be made much more propitious, much more responsive, much more encouraging, and in this matter all of us have a responsibility.

From the vantage point of mid-twentieth century, we may take a peep into history to learn the nature of the causes which operated inexorably through the various epochs to give science and technology the dominant position they have come to occupy today. History teaches us that science and society inevitably act and react on each other with consequences to both. While the impact of science has always been to revolutionize the conditions and conventions of society, the latter tends to resist the changes. Science has progressed in those periods of history, and in those geographical areas, where society has not only acquiesced in, but has actually encouraged science and its applications. While there is a prodigious amount of literature, including fiction, on the impact of science on society, comparatively little appears to have been written on the role of society in the evolution of science. Most historians of science take science as the main theme for exposition and everything else as secondary consequences flowing from discoveries, but such treatment does not permit the examination of the social background which made possible the great developments which have made the present, the Age of Science and Technology.

Science came into existence at a comparatively late stage in man's history, long after religion, long after man had adapted himself to community living, and only after he had outgrown the anti-scientific tendencies and inherently false approaches of primitive cultures. It developed independently of the useful arts, but only after the social organization had created a class of thinkers with sufficient leisure and intellectual curiosity to inquire into and understand the world of Nature. The great founders of science sought intellectual satisfaction and no more, only theoretical, contemplative *Weltanschauung*. Practical applications of knowledge were not their concern. This disinterested desire "to know, to understand" has continued to be the main impulse actuating scientists in their discoveries from the ancient period down to the present day. It is stated that one of the rare occasions when Newton laughed was when a friend, to whom he had lent a copy of Euclid's *Elements* asked him of what use or benefit in life the study of the book would be!

The possibilities of applying the method of scientific deduction for practical ends were recognized and demonstrated even in the heyday of Greek civilization, as for instance, by Archimedes, although they were not extolled or made much of by the scientists themselves. We know, on the authority of Virgil, that the seed of technology was sown at a comparatively early period in history. Due to the paucity of records in the pre-printing age, a proper appraisal of the developments in the earlier periods has not been possible. The social environment from the time of the Italian Renaissance onwards became favourable for technological adventures in Europe, and great writers of the period acclaimed the importance of discoveries and inventions. It was during the Renaissance period that people in Europe threw off the yoke of Middle Ages and the restraining bonds of theology. The French Revolution found use for physicists and chemists and the New Republic 'hired' them for systematizing weights and measures. In the age of the Industrial Revolution, the rule of aristocracy bowed down before the rise of the middle class. The practical applications of science gained emphasis over the disinterested pursuit of knowledge and social support for science became available. The rise of capitalist industrialism created a demand for inventions and the secular universities which came into existence gave a dominant place to science teaching and scientific research. The potentialities of science for catering to the material comforts of man came to be deliberately explored.

The march of civilization in the West since the nineteenth century has become inevitably bound with progress in technology. The tools and instruments which technology designed and fashioned are employed for probing more penetratingly into the realms of Nature ; thus helped, scientific research has been producing results which technology utilizes to advance material civilization. Marching in step, and in resonance, science and technology have ventured into new horizons producing marvels of human ingenuity. The pace of development is so quick, that it has become difficult for any scientist to keep track of advances even in his own limited field. Discoveries of today become the nucleus of a new science of tomorrow. The two World Wars provided proving grounds for technological creations, and the world witnessed with surprise and dismay, the powers which science and technology have unleashed ; they demonstrated, at the same time, in a most eloquent way, the possibilities of science for achieving peace and plenty and for making man's life rich and meaningful.

Science has emerged as a carrier of a new socialism, realistic in emphasis and rationalist in aim. In an astonishingly short period it has wrought radical changes in the patterns of industry and in the organization of science itself. The scale of scientific and industrial activity outgrew, long ago, the social institutions which gave rise to the Industrial Revolution. Research has come to be recognized as an industrial asset, and invention as an occupation of professionals. Laboratory research has found new meaning and new purpose.

It is not my intention today to discuss the implications of the achievements of science and technology in Western countries : my purpose is rather to emphasize that social awareness and social support have determined the progress and direction of science. If history has a lesson, it is this : everything that sustains and progresses comes as an upsurge from within, not as a result of something imported or invited, from without. Nothing sustains unless it is *of* the people and *by* the people.

THE PRESENT POSITION

We started with the premise, which in the context of the present situation has the status of an axiom, that the rapid advancement of science and technology is a pre-requisite for the development of the nation's material resources and economic welfare. We have emphasized the lesson of history that such advancement can come only when the efforts of scientists are backed by social support. On our innate ability to achieve results there can be no doubt ; we are endowed with an abundance of natural resources and we have a rich wealth of human talent ; we have the tradition for objective inquiry and acquisition of knowledge. Where we have lagged behind is in the application of knowledge to useful arts, and the establishment, through such application, of industrial production on a continuously progressive basis. While nothing is to be gained by deploring past neglect, the awareness it has engendered should spur us to action and promote science and technology boldly and with determination.

The need for improving industrial productivity has always existed ; it has now acquired urgency. We have hitherto sought inspiration from outside. We have imported plant and machinery, know-how and expert assistance. Perhaps this has been necessary in the circumstances. The result has been that the larger mechanized industries of India are, by and large, those which have been developed in other countries. Those based on indigenous inventions are few and far between. In the context of the new socialistic trends which permeate western technology, a liberal amount of assistance may be forthcoming. We, no doubt, seek knowledge, wisdom and friendship from whatever source they are to be had, but like the bee gathering nectar from whichever flower it is available, and transforming it into honey which is entirely its own, we should adapt such assistance to our own needs and requirements, and evolve a pattern of industrialization which we can call our very own. This will be possible only if we succeed in developing science and technology. Scientists and technologists have thus a responsibility, challenging but meaningful and with potentialities of a great achievement.

The contemporary scientific scene in India is one of considerable complexity. On the one hand, we are faced with a shortage of personnel with specialized skills and on the other, we are confronted with fragmentation of science and the need for liberalizing the education of the scientist so that he may combine knowledge with wisdom, expertise with vision. We are witnessing the peculiar spectacle of technical men being weaned away to other walks of life ; our universities and technological institutions are being depleted of their best teachers who find more gainful employment in Government departments and industrial establishments. Research results of proved value remain unutilized by industry, while the hunger for new processes and techniques continues unabated. All these may be signs of a fast developing techno-economy, but the problems are real and we shall be open to the charge, by posterity, of indecision and pusillanimity if we do not find satisfying solutions for them expeditiously.

The systematic promotion of improvements in production—agricultural, industrial, or otherwise—has created a continuously rising demand for the services of persons trained in a variety of skills and knowledge. While much has been done, and is being done, to train personnel, the real solution can emerge only when a serious effort is made to seek out all those who have the talent to profit by a scientific career. In a country richly endowed with human wealth, there can be no dearth of men and women gifted with curiosity and imbued with a passion for inquiry. The task is to stimulate these human endowments wherever they lie latent. No systematic 'talent search' appears to have been so far undertaken on a nation-wide scale. No effort has been made to tend and nourish the talents, abilities and aptitudes of the youth and kindle their enthusiasm to the delight of learning, at first hand, something new about Nature. It is time that we thought of enlisting new colleagues among the youth to help explore science in its diverse aspects. Each one of us should undertake, in a spirit of dedication, the task of mobilizing the untapped resources of the nation and guide the new recruits to the high adventure of discovery and invention.

The demand for personnel has outstripped the facilities available for training and has necessitated a revaluation of our training programmes. We need an increasingly large number of teachers and scholars, research scientists and engineers, doctors and public health specialists and persons equipped to manage, lead and venture into new enterprises. The process of equipping large numbers of men and women to undertake tasks with knowledge, competence, initiative and enterprise is a matter of vital concern. The levels of accomplishment called for must be achieved with the resources we have. Our academic institutions and research organizations must be husbanded with insight and imagination. We should initiate a system of interchange of scientists and specialists between universities and research laboratories on the one hand, and between these and industry on the other. I have, on many an occasion, emphasized the need for building up a system of exchange of personnel between organizations engaged in training and those concerned with utilizing personnel, not only for vitalising individual institutions, but in the overall interest of inducting a sense of urgency into our programmes and achieving the targets demanded by the realities of the situation.

The tempo of the recruitment of scientific and technical personnel must be accelerated. This problem is urgent in the context of the dire need for the services of the all-too-scarce specialists—be they scientists, engineers or technologists—in national reconstruction tasks, for which the demand is large and the supply limited. We must determine the pattern of their deployment which would yield results from the point of view of both immediate and future requirements. Several Indian students with brilliant academic records have received or are receiving advanced training in laboratories and institutions in India. A large number of our young men and women are at present undergoing specialized training in various countries abroad. The placement of such personnel is engaging our attention. But our administrative procedures must be considerably simplified so that such personnel may be absorbed in appropriate places as soon as their training is over.

We are also concerned with shortages which exist at the level of high intellectual talent. There cannot be enough talent at this level at any time, and shortages will always exist. A small percentage at this level would be in the genius category, and all that we can and ought to do is to create the 'climate' under which geniuses uncover themselves.

I have often asked myself the question whether the conditions in which some of our able scientists are functioning are such as to get the best out of them. Too often we load the scientists with routine and other non-productive work. Our administrative machinery has not been designed to encourage just that 'out-of-the-wayness' or 'idiosyncracy' of the scientist, which distinguishes him from the ordinary man, and guided by procedures and precedents, it tends to bring scientists and others into a common rigid steel frame. It is well to remember that scientists are not just the ordinary run of people. They are not normal, in the sense that they seek to do things which are out-of-the-ordinary and it is precisely such adventures that are rewarding. Administrative procedures, which perhaps are necessary elsewhere, may prove too cumbersome to the creative genius of the scientists.

Administration should recognize and respect the interests of scientists and permit them to explore the areas in which their talents lie. As Dr. Conant, President of Harvard, observed sometime ago, there is only one proved method of getting results in scientific research: picking men of ability, backing them heavily, and giving them freedom to pursue whatever path appears to them most promising. Science is a delicate plant, exacting in its demands and can thrive only in the warmth of encouragement and deference. Wise administration can go a long way, a very long way, in providing conditions which would enable scientists to give of their best to the nation.

Scientists should also recognize that besides contributing to the enrichment of different fields of research, they have also certain extramural responsibilities, as for example, in the training of personnel in its manifold aspects and in the creation of public understanding of science, which they should accept in a spirit of enlightened self-interest. Too often we hear of lack of buildings, lack of equipment, lack of funds, and so on; what we really lack is the determination TO DO. Buildings and equipment do not make for scientific progress. I have often observed that quite remarkable work is turned out in plain simple laboratories, some of them even improvised and many not lavishly equipped or housed. A good many items of equipment can be designed and fabricated with available facilities without having to wait for import licences or provision of foreign exchange. We have to woo science with greater ardour, greater devotion and greater faith than hitherto, if our approaches are to be favoured and rewarded.

From whatever angle we survey the contemporary scene—personnel requirements, training of scientists, liberalising education, or any other—we are impressed by the urgency for a deeper comprehension of the fundamental needs and for relating knowledge with action. Science, technology and invention are the most important elements for improving the material welfare of the people and their development is conditioned by social purposes and social support. Without such support, science and technology cannot find the means or the inspiration for development. Without a well-defined social purpose, the search for technological facts will degenerate into dilettantism; and all measures which we may formulate to promote science and technology in isolation, will prove inconsequential. The clear requirement, then, is to exert and spread the understanding of science among the people so that, assured of public support, we may move with freedom and explore the beneficent results which science and its applications make possible.

SOCIAL UNDERSTANDING OF SCIENCE

Penetrating minds have held the view that the consequential value of the scientific way of thinking transcends the material benefits which science has conferred on mankind. It is to the propagation of this sustaining value of science that scientists must address themselves. It is a big responsibility which can be discharged only when the scientists revise their 'ivory tower' attitude and recognize that their responsibility to society is no less important than their loyalty to science and that there is no conflict between the two.

Science is not merely thematics, that is, the study of certain subjects. It is study by a certain method which emphasizes observation and experiment, reasoning and deduction, a method based on facts, their sequence and relative significance. The scientific method enjoins one to be critical of all things and accept only facts which are amenable to verification and test. It has a place as much in the education of the scientist and technologist as of the craftsman and citizen, whether he be employed in a skilled or unskilled job, in agriculture or administration.

Everyone longs in a vague sort of way, for an understanding of science, and this has to be satisfied, not by providing bits of information, but by making him aware of the basis on which science rests, the method by which rational knowledge is gleaned. The real danger to education is to mistake the provision of information for the imparting of knowledge. It is easy to acquire strands of information from diverse sources, but that does not help in understanding science. The greatest common factor of all sciences is the method; and the mind that has been trained in the scientific method and habituated to form judgements on the basis of facts, their relative sequence and significance, converts all that passes through it into science. It is such a mind that is best equipped to meet the challenge of change in a dynamic and forward-looking society.

The educational task involved in promoting the understanding of science is a gigantic one, but all the attention that is devoted to it and all the effort expended on it will prove most rewarding. A primary requirement is to dispel the popular conception that science is some sort of a super-discipline practised by specially trained people using very complicated precision instruments. This incorrect, if exalted, view of science has tended to separate the scientist as a class from the people. Science is a very human enterprise and is basically a methodological approach to understanding. The best way to obtain an insight into the method and to acquire the habit of dispassionate thinking is to take a live interest in some small area of natural phenomena. The material for science is co-extensive with the whole physical universe and there are many problems which are amenable to investigation by tools and techniques which are ordinarily available to the layman. I may mention, as instances, observations relating to weather phenomena, variable stars, bird migrations, distribution of plants and animal species and minerals. The opportunities for study are limitless and the whole book of Nature is open to those who possess an inquiring mind and are acquainted with the alphabet of science. Science has room for everyone for all time, and it stands to gain by mass-participation in its work. Mendel, Darwin and many other names that adorn the book of discovery were amateur scientists.

I have referred to amateur science as one of the means of spreading an appreciation of the scientific method. There are, no doubt, other means open, which can be worked out by scientists and educationists working in concert. The important thing is to stimulate interest in enquiry among the people as a whole, particularly among the children, and no effort should be spared to attract the youth to the vast field of science ; it is to the youth we look for promoting the resurgence we are striving for.

The 'climate' for this great educational task has become particularly favourable since Independence. The nation is, as it were, in a ferment and unprecedented enthusiasm for economic reconstruction permeates all sections of society. Craft-centred instruction has become the pattern for primary education throughout the country and a bias for practical and social values is being inculcated, along with the teaching of the Three R's, from the earliest stages. The Five-Year Plans are bringing goals and targets into the picture, and working to a time schedule to attain predetermined objectives has become the economic philosophy of the nation. The introduction of the national calendar, the decimal coinage, and the metric weights and measures has brought in new systems and standards in social transactions. A new order geared to progressive ideals and ideas is coming into existence. The ground has been prepared for the spread of the understanding of science and through it, the spirit of inquiry, the critical habit of mind, and rationalist approach to practical affairs.

The duty of scientists in promoting the public understanding of science assumes importance in the context of the newer Promethean creations of technology, which are being released in breathless succession. Francis Bacon stated that "God has placed no limits to the exercise of the intellect He has given us on this side of the grave". Bacon envisaged the exercise of the intellect only for the emancipation of man. The newer developments, from the point of view of knowledge gained, have extended the glory of man, but they have inculcated, at the same time, a fear of knowledge which has potentialities for more harm than good. In this situation of uncertainty and doubt, safety lies in the collective social wisdom, for it alone can determine the direction of technological applications and can hinder or nullify injurious experimental ventures.

THE TASK BEFORE US

If our faith in science and technology as a promoter of public good is sincere, then our clear duty is to create those conditions which will permit us to pursue science and promote its applications. The lesson of history and the requirements for scientific progress all point to the need for promoting the public understanding of science, and it is to the creation of this understanding that we should dedicate ourselves. Our success will be determined by our sincerity and zeal, and in tackling a problem of this magnitude, we should act collectively as disciplined armies, not individually as 'guerilla' fighters. Scientists, engineers and technologists must willingly and gladly shoulder this responsibility. Let us get together without loss of time, formulate programmes of action, and strive forward with all the zest and zeal at our command, to achieve the desideratum for progress.

The finances required for the overall progress in science will no doubt be large, but no impassioned plea is called for, to convince the people of this great country that development is possible only through science. Our resources are perennial, and if we reckon even at one rupee *per capita* which is less than half of one per cent of the national income, we should be able to find funds within our own means and resources to make a headway.

Scientists and technologists in India occupy a position of trust, and the country as a whole avidly awaits the benefits that stem from their work. Our Prime Minister, Shri Jawaharlal Nehru, has, time and again, stressed the important role which scientists and engineers have to play in the reconstruction of India and has made appreciative references to their work. We should not allow this sense of importance to lull us into complacency. Let us remember that we are on the threshold of an era of great and revolutionary changes in our land. It is not every generation that has the challenging opportunity to serve the motherland.

Most of this onerous responsibility will devolve on the shoulders of the younger generation and it is to this generation we look for leaders and the rank and file of builders of resurgent India. I take this opportunity to appeal to the youth of this country to rise to the occasion and equip themselves for the tasks of tomorrow. It has been a great blessing to us that, in our Prime Minister, we have a stalwart champion of the cause of science, and all of us can set about our tasks with the firm conviction that we enjoy his invaluable support in our endeavours.

SECTION OF MATHEMATICS

President : **B. S. MADHAVA RAO**

Presidential Address

MODERN ALGEBRA AND THEORY OF ELEMENTARY PARTICLES

1. INTRODUCTION

The ever increasing use of the deepest and the most abstract parts of mathematics has been a remarkable feature of modern physical theory. Mathematics of the present day abounds with abstract notions like abstract sets, abstract spaces, abstract algebra, abstract analysis, and so forth, and equally so in the highest departments of modern physics like relativity and quantum theory, it appears that the abstract point of view is likely to yield the most fruitful results. It is also true that the more varied and more subtle contributions from mathematics are in proportion to the wider range of physical fact acquired as a result of more and more accurate experimental research in fields involving a progressive increase in the complexity of experimental facts.

This increase in the application of abstract mathematical notions can be traced to a large extent to the change brought about by quantum mechanics in the meaning to be attached to physical quantities. This basic importance of mathematics arises mainly on account of the fundamental notion of complementarity which, when pressed to its logical conclusion, implies that natural science is not nature itself, but a part of the relation between nature and man, and is, therefore, dependent on man. Thus the understanding of the symmetry laws of nature is nothing but the attainment of the transparent clarity of a mathematics which governs these possible laws. In the old classical physics, a physical quantity was considered as the exact equivalent of the mathematical function assigned to the observable. Mathematics now abounds with concepts which are not mere functions, and yet allow the assignment of numbers under certain conditions, *e. g.* matrices, differential operators, groups, integral operators, and tensors. What quantum mechanics has done is to emphasise that the definition of physical quantities as such operators should be taken, not in a symbolic, but exact sense. With this interpretation, an operator may yield not one but a large set of numbers which can, however, be consistently used with the aid of a statistical theory. In the language of mathematics, we might say that the number concept has been replaced by the more general concept of aggregates.

The widening of the concepts of theoretical physics is bound to be of significance to the mathematician also. The history of mathematics is a clear witness to the fact that stimulating questions arising in the application of mathematics to other fields spur on the progress of mathematics itself. In some concepts like analysis, one can even say that mathematics owes more of its advance in these branches to the physicist than to any other agent. We thus recall how the problem of heat conduction, and wave motion led to the development of the function concept, and the introduction of orthogonal series, which are basic elements of present day analysis. Dirichlet's problem in potential theory had a profound influence on the calculus of variations, and led to the theory of integral equations. In the masterly hands of Hilbert, this became a theory of orthogonal transformations, and reduction of quadratic forms, and created the atmosphere which stimulated basic discoveries on function spaces including the abstract Hilbert space. It is a remarkable, but a common feature in physical theory, that while these developments excited by physics were taking place in mathematics, the physicist himself had little or no interest in them, until the advent of quantum mechanics compelled him to look at them more seriouly. It is common knowledge, nowadays, that the analytical problems of quantum mechanics can be thought of in terms of linear transformations in an abstract Hilbert space.

2. ALGEBRA AND PHYSICS

On the other hand, the relationship between algebra and physics has been a rather loose one in the earlier years. It is no doubt true that the theory of groups has always played an important part in theoretical physics, as for example, in the domains of molecular physics, crystal physics, and chemical physics. Also the analysis of space and time has involved group-theoretic considerations, and classical dynamics has employed group methods through transtormation theory, and many recent studies have freely used topological notions. But it is only in the last two decades that the more profound portions of the theory of groups, and some other parts of modern algebra have played notably enhanced roles in relativity and quantum theory.

In this case it is perhaps not true, as in the case of analysis, that these branches of group theory and algebra were inspired by the physicist. The researches of Noether, Weatherburn, Dickson, Artin and others on abstract algebras, of Frobenus, Schur, and Weyl on the theory of group representations, and of Cartan on continuous groups were carried on independently as a result of the fusion of several fundamental ideas in mathematics itself. These have now found applications in quantum mechanics, and this relationship is attractive from many points of view.

It is, however, true that in recent years, these and many other branches of mathematics have made advances in some directions as a consequence of this relationship to physics. These advances have resulted sometimes as a consequence of the methods of rigour employed in pure mathematics. In the work of many theoretical physicists one notices sometimes that heavy emphasis is laid on non-invariant (*i.e.* to say possessing no physical significance) properties of the matrices under consideration, and at the same time, their invariant properties are insufficiently explained. Very often, the colourless pseudonym "matrix" hides a multitude of spin tensors of widely varying nature, the properties of which remain almost entirely in the dark. Even more undesirable is the fact that relations among spinor quantities are often written in non-invariant form, a circumstance which naturally does not permit the disclosure of their physical meaning. As examples arising out of such rigorous treatments, we might mention the special types of non-associative algebras including the quantum mechanical algebra, theory of rings of operations, simply reducible groups and their representations, the new methods of abstract lattice theory resulting from the discussions relating to the logic of quantum mechanics, the general theory of spinors, the theory of gauge groups, and above all, the theory of semi-simple Lie groups of which Lorentz groups are particular types, and the more general theory of topological groups, and their different representations.

3. CONCEPT OF ELEMENTARY PARTICLES

The subject of elementary particles of nature holds the centre of interest in physics today, and is a striking example of knowledge gained by an intimate fusion of experimental and theoretical methods, specially the relativistic and quantum theories. While the very concept of elementary particles is quantum mechanical in origin, it is certainly true that relativity has been crucial for further developments in quantum theory. Thus, starting from the notion of a photon, the relationship $E = cp$(including $E = mc^2$) between the energy and momentum of a particle is relativistic. Another example is the de Broglie relation $p = h/\lambda$ which followed from Planck's relation $E = h\nu$ on the basis of Lorentz invariance. A third example is the relativistic quantum mechanics inaugurated by Dirac, which led to the concept of anti-particles and to the production and annihilation of pairs, by turning the apparent paradox of negative energy states into the most remarkable success of the theory. In addition to being crucial for the development of quantum theory, relativity has provided some general results which give a deeper insight into the structure of quantum mechanics as illustrated, for example, in the connection between Lorentz invariance and the conservation laws of quantum field theory. A brilliant example of this connection is Pauli's analysis of the relation between spin and statistics, which is one of the most important applications of the theory of representations of the Lorentz group.

With the growth of experimental techniques in cosmic ray work, nuclear reactions, and specially with the completion in recent years of the cosmotron and bevatron, a host of new elementary particles have been discovered, and it is the fashion nowadays to classify them into the old, and new or strange particles. Another classification is to group them under the categories of well-established particles, well-established but not well determined ones, and the less well-established ones.

The oldest known of the old particles are the *electron* and the *proton* with charges $-e$ and $+e$, masses m_e and $m_p \sim 2000 m_e$ and the same spin 1/2, associated with the constant angular momentum $h/2$. The proton-electron constitution of nucleii was rendered untenable as a consequence of Dirac's theory of the electron, and Pauli's relationship between spin and statistics *viz.*, that particles with integral spin obey the Einstein-Bose statistics, while those with half-integral spin obey the Fermi-Dirac statistics, and this led to the discovery of the *neutron* having nearly the same mass as the proton, no charge, and spin 1/2. Next, to explain the phenomenon of β-decay consistently with the proton-neutron constitution of nucleii, the *neutrino* with mass very small compared to m_e, if not exactly zero, spin 1/2, and zero charge, was postulated by Pauli, and the process of β-decay was described by

$$\text{neutron} \rightarrow \text{proton} + \text{electron} + \text{neutrino},$$

in consonance with the conservation of spin and charge. The next old elementary particle to be discovered was the *positron* with the same mass and spin as the electron, but charge $+e$, and this discovery and the demonstration of the processes of annihilation and pair-creation in cosmic ray showers provided a remarkable confirmation of Dirac's relativistic wave equation. The neutron and position also led to a radical revision of the concept of elementary particles *viz.*, that they cannot be considered permanent and immutable, but take part in transformations among themselves. The next elementary particle was the *meson* postulated by Yukawa to explain the exchange nature of nuclear forces changing a proton into a neutron, and a neutron into a proton every time these particles interact, the intermediaries in these interactions being the mesons with charges $\pm e$, integral spin, and mass about 200 to 300 m_e. The discovery of particles in cosmic radiation with masses of this order must be regarded as a confirmation of the general idea of the Yukawa theory. The β-decay is fitted into this theory by assuming that the original process takes place really in two steps, as for *e.g.*,

neutron→proton+−ve meson, and −ve meson→electron
+neutrino,

the latter corresponding to a spontaneous decay of the meson, thus introducing a new feature into the concept of elementary particles. This meson may be considered as a bridge between the old and new particles, and the neutrino postulated in the β-decay, and the spontaneous decay of the meson has always been a mysterious particle, and can well be considered as an old as well as a new particle.

Coming now to the new particles it is best to group them on the basis of their rest masses. On this classification, the old particles *viz.*, the photon r^0, the neutrino γ^0, the electron e^-, and the positron e^+ could all fall in the first group of particles with masses less than or equal to m_e. The second group, termed the group of *L-mensons*, has for its most important member the π-meson which is responsible for the main features of nuclear forces, with mass about $273m_e$ and existing in the forms π^+,π^- and π^0, all having spin zero. This second group of *L*-mesons is characterised by particles having masses between m_e and m_π, and contains another member, the μ-meson well known in cosmic radiation at sea level, of mass about $207m_e$, and existing as a well-established particle in the forms μ^+ and μ^- both of spin 1/2. The third group consists of the *K-mesons*, the new particles discovered in cosmic radiation with masses intermediate between $m_\pi \pm$ and m_{proton}. During the last few years, at least eight different *K*-mesons have been discovered with different decay modes, but the well-established ones among them are the τ^+ and τ^- mesons with masses about $966m_e$, and both of spin 0, and the θ^0-meson of about the same mass as the τ-mesons, and a spin which is integral but $\neq 1$. The fourth group would consist of the old and well-established particles, the proton p^+ with mass $m_p \sim 1836m_e$, and spin 1/2, and the neutron n^0 with mass $\sim 1839\ m_e$, and also spin 1/2, both these particles being designated as *nucleons*. The fifth group consists of the so-called *hyperons* (or *Y*-particles) mainly resulting from controlled bevatron experiments, with masses lying between m_p and $m_{deuteron}$, and among the well-established hypersons can be listed four, viz., the Λ^0 with mass $\sim 2181m_e$, the $\Sigma^{\pm}$ both of mass $\sim 2327m_e$, and the Ξ^- of mass $\sim 2586m_e$, all the four hypersons having half-integral spin.

Mention may also be made of the particles with properties *not so well determined*, viz., the five types of *K*-mesons characterised by their decay products, and made up of the so-called $\theta^{\pm}$, $\tau^{1\pm}$, and $k^{\pm}$ mesons. In the same class would fall the *anti-proton* p^{-} (recently produced at Berkeley) with mass same as m_p to within ±5%, spin 1/2, and providing another brilliant confirmation of Dirac's theory. If this theory be generally applicable, every particle should have a corresponding anti-particle, and there should also be phenomena of creation and anihilation of pairs. Even a neutral particle as, for instance, the neutron which has a magnetic moment representable by a closed current must have its counterpart obtained by inverting the current, thus giving rise to an *anti-neutron*. The same is true of the neutrino also if it be associated with a magnetic moment, however, small, and even if the magnetic moment were exactly zero, the anti-neutrino could still be defined as a hole in the negative energy state of the neutrino wave equation, and this is the more usual definition of an anti-particle. The notion of anti-particles also raises the interesting question about the distinctness or otherwise of the particle and antiparticle. Some recent conjectures have been made that $\bar{\pi}^0 \equiv \pi^0$, while the $\bar{\nu}^0$ and ν^0 are different particles (the bars denoting anti-particles.).

The discovery of the new particles has emphasised the fundamental importance of the knowledge of interactions between them, and their decay modes and this emphasis has to some extent changed the weight of the old theoretical arguments, and the lines of experimental research. Also, the abundance and complexity of these interactions have stimulated tremendous activity among experimenters, and caused a great flow of interesting speculations from theoretical physicists. While a correct theoretical understanding is obviously a matter for the future, mention may be made of recent attempts of a phenomenological nature undertaken to elucidate the symmetry laws or invariance properties that hold in such interactions. Regarding the nature of the interactions, it has been found that they can be classified into three categories, the strong, the electromagnetic, and the weak ones, the first type having intensities of around 1 to 10^{-1}, the electromagnetic interaction having 10^{-2}, and the third type having intensities ranging from 10^{-12} to 10^{-14}. Designating the *K*-mesons and the hypersons as *strange particles*, examples of such weak interactions are provided by the decay of strange particles (for e.g. $\tau^{+} \rightarrow \pi^{+} + \pi^{+} + \pi^{-}$; $\theta^{0} \rightarrow \pi^{+} + \pi^{-}$; $\Lambda^{0} \rightarrow p^{+} + \pi^{-}$; $\Sigma^{-} \rightarrow n^{0} + \pi^{-}$, and $\Xi^{-} \rightarrow \Lambda^{0} + \pi^{-}$) the β-decay, the μ-meson decay viz., $\mu^{\pm} \rightarrow e^{\pm} + \nu^{0} + \nu^{0}$, the π-meson decay viz., $\pi^{\pm} \rightarrow \mu^{\pm} + \nu^{0}$, and the μ-meson-nucleon interaction. The wide gap separating the weak interactions from the other two, and the fact that while the production of the strange particles falls into the first class, their decay falls into the third, are so striking as to suggest that there should be a fundamental reason for these discrepancies.

Coming now to the phenomenological invariance properties, one notices first of all that the well-established law of the conservation of the number of nucleons necessitates the assignment of a "heavy particle quantum number" N to all elementary particles. A consistent assignment is possible by putting $N = 0$ for the first two groups of the mass classification, $N = \pm 1$ for nucleons and anti-nucleons respectively, $N = 1$ for the hyperons, and $N = 0$ for the K-meson class. Also the charge is conserved for all interactions. There has also been noticed another conservation law if one limits oneself to the strong and electromagnetic interactions only viz., the conservation of "*strangeness*" S which is satisfied by assigning $S = 0$ to the nucleons and π-mesons, $S = 1$ to K^+ and K^0, $S = -1$ to K^-, K^0, Λ^0, Σ^+, Σ^0, and Σ^{-1}, and $S = -2$ to Ξ^-. The weak interactions violate this strangeness conservation. Finally taking the strong interactions only into consideration, it is found that the third component τ_3 of the isotopic spin quantum number (given by the Pauli 2×2 spin matrices) is invariantly connected with N and S by the relation

$$\tau_3 = Q - \frac{N}{2} - \frac{S}{2} \qquad \dots \quad (1)$$

where Q is the total charge expressed in multiples of $|e|$.

In the above, we have not mentioned invariance under spacetime transformations, but of recent interest, specially in the case of weak interactions is the concept of *parity* which is ±, according as the wave function associated with the particle does not or does change its sign under space reflections alone. From the experimental information so far available, the well-established L-mesons have all a negative parity, both the $\tau^{\pm}$ are of negative parity and θ^0 is perhaps of positive parity. The question of invariance of parity in weak interactions has very recently been tested by suitable experiments suggested by Lee and Yang, and the important discovery of parity-nonconservation in such interactions has been made. This naturally raises questions of invariance under time reversal, and charge conjugation, and combinations of these operations. We will return to these questions in the last section.

It appears probable that these new points of view do not demand a radical revision of quantum concepts, but a careful reconsideration of the algebraic nature of the transformations under the full Lorentz group, its several sub-groups, and also under charge conjugation. It would, therefore, not be inappropriate if we considered in the next few sections the results already known about the relativistic quantum theory of elementary particles.

4. RELATIVISTIC QUANTUM FIELD THEORY

This theory consists essentially of two stages in its application, the c-number theory with the wave functions and field equations for the particles satisfying the postulates of special relativity, and the q-number theory making a transition to the particle picture obtained by using the quantum conditions expressing the non-commutation of field functions at different points of space-time. Such a passage from the c-number to the q-number theory, a transition from a one-particle to a many-particle picture is called double quantisation.

The essential steps in the c-number theory are the setting up of a Lagrangian which is invariant for transformations of the proper Lorentz group *i.e.* the continuous Lorentz group L_4 in which no reflections are included, the derivation of the field equations from a variational principle, the setting up of the energy-momentum, and angular momentum tensors, and leastly the setting up of a current four-vector by assuming the invariance of the Lagangian against gauge transformations, and dividing the field quantities into $U(x)$, their conjugates $U^*(x)$, and the real quantities $V(x)$. Since the field equations are derived from a Lagrangian, the field quantities themselves should transform according to irreducible representations of the group L_4. Such quantities are, as is well known, the spinors, and the field quantity can be written as $U(j, k)$ characterised by two indices j and k corresponding to spinors with $2j$ undotted and $2k$ dotted indices, and symmetric in them separately. Using the Clebsch-Gordan rule for the reduction of product representations, and the situation in the case of the subgroup of space rotations, one defines the spin of the particle as $j+k$. For the case of $2j+2k =$ even, the spinors reduce to the ordinary world tensors, but not for the case $2j+2k =$ odd. Working with these field quantities, we find the general results that for particles of half-integral spin, the total energy is not necessarily positive and for integral spin the charge density is not necessarily positive. Going to the q-number theory, and using the fact that the expressions for the non-commutation of the field quantities at different points should themselves satisfy invariance relations, these expressions can be written in terms of the bracket forms

$$[U(x), U^*(x)]^{\pm} = D(x, x') \qquad \dots \quad (2)$$

the $+$ or $-$ being taken according as the particles satisfy the Fermi-Dirac (F.D) statistics, or the Einstein-Bose (E.B.) statistics, where, further, the transformation properties of the U's under L_4 also require that the D's should transform in a certain way. By merely considering the algebraic nature of the transformations of the D's under L_4, with the further requirements that D is the function of the invariant distance between x and x', that $D = 0$ if they be separated by a space-like distance, one is led to the general results that for integral spin, quantisation according to F.D. statistics is not possible, and that for half-integral spin there is no algebraic contradiction in either statistics being satisfied, but the removal of the negative energy difficulty is not possible if one uses the E.B. statistics. These results are purely negative, but the actual carrying through of the quantisation shows that for half-integral, and integral spin particles a stisfactory theory can be obtained using respectively the F.D. and E. B. statistics.

5. THE PARTICLE ASPECT

The general theory sketched in the previous article enables the setting up of a wave equation satisfied by the spinors, the equations being of the second order, and in order that the theory may represent particles of a single spin, it is necessary to assume, besides the symmetry of the spinor in the dotted and un-dotted indices, that the spinors $p^{\dot{\nu}\rho}\, a^{\ddot{\mu}\ldots}_{\rho\delta\ldots}$, and $p_{\dot{\nu}\delta}\, a^{\ddot{\nu}\ddot{\mu}\ldots}_{\lambda\rho\ldots}$ where $p^{\dot{\nu}\rho}$ is the gradient spinor) should also be symmetrical. This makes it possible to go from a second order wave equation to a system of two first order equations of the type

$$\left.\begin{aligned} p^{\dot{\nu}\rho}\, a^{\dot{\lambda}\dot{\mu}\ldots}_{\rho\delta\ldots} &= \chi b^{\dot{\nu}\dot{\lambda}\dot{\mu}\ldots}_{\delta\ldots} \\ p_{\dot{\nu}\rho}\, b^{\dot{\nu}\dot{\lambda}\dot{\mu}\ldots}_{\delta\ldots} &= \chi a^{\dot{\lambda}\dot{\mu}\ldots}_{\rho\delta\ldots} \end{aligned}\right\} \quad \ldots \quad (3)$$

($h\chi$ = rest mass of the particle)

where the spinor b satisfies the same conditions of symmetry as a. The cases where a has $2k$ undotted, and $2k-1$ dotted indices, or $2k$ dotted and $2k-1$ undotted indices according as the spin is half-integral or integral respectively, are specially simple, and denoting the spinors in this case by $a^{(0)}$ and $b^{(0)}$, they have the property of going over into each other by reflections of space-time. In the integral case $a^{(0)} = b^{(0)}$, and in the half-integral case $a^{(0)} \rightleftarrows b^{(0)}$ under reflections, so that together they form a system invariant under the Lorentz group consisting of L_4, and the reflections. The first order wave equations in them are then said to be of the Dirac particle type. Using the general result of semi-simple groups that, if the matrix commuting with all the matrices of an infinitesimal product respresentation is brought to the diagonal form, the product representation is simultaneously split up into its irreducible components, it can be shown that the above type of equations can be reduced to a type involving only one spinor index viz.,

$$\left.\begin{aligned} p^{\dot{\nu}\rho}\, \psi^{A}_{\rho} &= \chi\psi^{\dot{\nu}} \\ p_{\dot{\nu}\rho}\, \psi &= \chi\psi^{A}_{\rho} \end{aligned}\right\} \quad \ldots \quad (4)$$

where A and B indicate that ψ involves magnitudes like A_s^r and B_j^i, and the equations are to be treated as matrix equations. Finally the two equations can be combined into one single equation, the famous Dirac equation representing the particle aspect of elementary particles viz.

$$\partial_\mu \beta_\mu \psi + \chi \psi = 0, \qquad \left(\partial_\mu = \frac{\partial}{\partial \chi_\mu}\ ;\ \mu = 1, \ldots 4\right).$$

where for the case of spin 1/2, the Dirac matrices β_μ satisfy the commutation relations

$$\tfrac{1}{2}(\beta_\mu \beta_\nu + \beta_\nu \beta_\mu) = \delta_{\mu\nu} \qquad \ldots \quad (5)$$

In virtue of these relations, the system of the 16 members 1, β_μ, $\beta_\mu\beta_\nu$, $\beta_\lambda\beta_\mu\beta_\nu$, and $\beta_1\beta_2\beta_3\beta_4$ form a hypercomplex system (the Dirac algebra). As is well-known the theorems relating to the representations of a finite group can be extended to group rings and hence also to a system of hypercomplex numbers or an algebra, satisfying certain conditions. Applying the theorems which hold in the case of a semi-simple algebra of which the Dirac algebra is a particular case, it is very simple to prove that this algebra has only one irreducible representation of order 4, showing that the Dirac equation is unique but for equivalence.

The question arises whether a particle aspect of the theory can be set up for particles of higher spins also. As is well-known, this is possible for the cases of spins 0 and 1. The second order wave equations in these cases with the field quantities being a scalar and four-vector respectively, can be put in the Dirac form with the β-matrices being 5-rowed and 10-rowed respectively, the commutation relations for both cases being combined in one single form :

$$\beta_\lambda \beta_\mu \beta_\nu + \beta_\nu \beta_\mu \beta_\lambda = \delta_{\lambda\mu} \beta_\nu + \delta_{\mu\nu} \beta_\lambda. \qquad \ldots \quad (6)$$

The β-algebra in this case can be shown to have rank 126, resulting in three representations of orders 1, 5, and 10 satisfying $1^2 + 5^2 + 10^2 = 126$.

I have considered some time back the question of extending this to the cases of higher spin. As a preliminary to this, it is necessary to derive commutation relations satisfied by the β_μ's and I have shown that we can derive such relations by making some general assumptions.

Let the infinitesimal transformation

$$x'_\mu = x_\mu + \Sigma\, \epsilon_{\mu\nu} x_\nu, (\epsilon_{\mu\nu} = -\epsilon_{\nu\mu},\ \text{numerical}) \qquad \ldots \quad (7)$$

correspond to the transformation $\psi' = A\psi$ of the wave equation with

$$A = 1 + \tfrac{1}{2}\Sigma\ \Sigma\, \epsilon_{\mu\nu}\, s_{\mu\nu}, (s_{\mu\nu} = -s_{\nu\mu},\ \text{matrices}) \qquad \ldots \quad (8)$$

where the $s_{\mu\nu}$ are the spin matrices. The general assumptions are that (i) the wave equation is invariant against L_4. This leads to

$$\beta_\lambda s_{\mu\nu} - s_{\mu\nu}\beta_\mu = \delta_{\lambda\mu}\beta_\nu - \delta_{\lambda\nu}\beta_\mu \qquad \dots \quad (9)$$

(ii) $$s_{\mu\nu} = K(\beta_\mu\beta_\nu - \beta_\nu\beta_\mu), \qquad (K, \text{ a constant}) \qquad (10)$$

(iii) each component of $s_{\mu\nu}$ satisfies the algebraic equation whose roots are the $(2f+1)$ eigen values of the spin operator ($f =$ spin).

These assumptions enable us to construct generalised algebras related to particles of arbitrary spin based on the commutation rules. These rules have been obtained, in particular, for the cases $f = 3/2$ and 2, and the algebra in the former case has been studied in detail, and it is shown that this algebra is the direct product of the Dirac algebra, and an associated ξ-algebra (a result true for general half-integral spin). The ξ-algebra is shown to have just three representations of orders 1, 4, and 5 such that the rank of the algebra is equal to 42.

Explicit matrix representations for the non-trivial cases of orders 4 and 5 have also been obtained.

6. PARTICLES OF REST MASS ZERO, AND THE GAUGE GROUP

The statistical interpretation of the wave functions appearing in the general field theory of section 4 requires that the Lagrangiam be invariant under the gauge transformations of the first kind satisfied by the field quantities viz.,

$$U(x) \to U(x)e^{i\alpha}\,; \qquad U^*(x) \to U^*(x)e^{-i\alpha} \qquad \dots \quad (11)$$

with α, an arbitratry constant in the case where no external fields are present. As already mentioned in section 4, the invariance of the Lagrangian under gauge transformations also leads to the possibility of setting up a current vector since such transformations express the non-measurability of the phase of the complex wave function of a charged particle. In the case of a particle of rest mass zero one has the physically significant result that the particle has to have only two independent and really different plane waves for a specified wave number and frequency. For this purpose, it is found necessary to add to (11) another kind of gauge transformation said to be of the second kind. Thus for example in the case of fields of arbitrary integral spin describing particles of zero rest mass, the field quantity would be a tensor $A_{\lambda\mu\dots\nu}$, and the gauge transformation of the second kind is defined by

$$A'_{\lambda\mu..\nu} = A_{\lambda\mu..\nu} + N_{\lambda\mu..\nu} \qquad \dots \quad (12)$$

where

$$\left.\begin{array}{l} N_{\lambda\mu..\nu\rho} = \dfrac{\partial c_{\mu..\nu\rho}}{\partial x_\lambda} + \dfrac{\partial c_{\lambda..\nu\rho}}{\partial x_\mu} + \ldots + \dfrac{\partial c_{\lambda\mu..\nu}}{\partial x_\rho}\,; \\ \Box C_{\mu..\nu} = 0\,;\; C_{\mu\mu..\nu} = 0\,;\; \dfrac{\partial C_{\mu..\nu}}{\partial x_\mu} = 0 \end{array}\right\} \quad \ldots \quad (12,a)$$

Similar gauge transformations of the second kind can be set up for particles of half-integral spin also, with the aid of spinors. In both cases we have to consider the transformations of the second kind in addition to (11) where α is now to be taken as an arbitrary function of space-time, and we are then led to only two independent components if we consider states which go into each other under such gauge transformations as equivalent.

7. NEUTRAL PARTICLES AND CHARGE INVARIANCE

The case of neutral particles corresponds to real fields with $U = U^*$. The original form with a complex U is equivalent to two real fields $V = V^*$, and $W = W^*$ with

$$U = \frac{1}{\sqrt{2}}\,(V+iW)\,; \qquad U^* = \frac{1}{\sqrt{2}}\,(V-iW) \qquad \ldots \quad (13)$$

the numerical factors being introduced for the sake of convenience of quantisation. A theory of neutrical particles can be obtained from (13) by striking out W and such a theory is called an "*abbreviated*" one. To find out whether this method of splitting into two real fields is possible in the case of a particle of spin 1/2, let us consider first the Dirac equation of the electron, and define the α, β matrices by $\alpha_k = i\gamma_4\gamma_k (k = 1, 2, 3)$ and $\beta = \gamma_4$. We can now introduce the Pauli C-matrix defined by

$$\beta^* = -C\beta C^{-1}\,; \qquad \alpha_k^* = C\alpha_k C^{-1} \qquad \ldots \quad (14)$$

and show that C exists, that $C^*\,C$ commutes with all the γ_μ, and is hence a constant and that C is symmetric, and hence can be so chosen that $C^*C = 1$. The C-matrix can be used to set up a Lorentz-invariant ordering between the solutions of Dirac's equation with positive and negative frequency viz,

$$u_-^* = Cu_+\,; \quad u_+ = C^{-1}u_-^* \qquad \ldots \quad (15)$$

such solutions being called *charge-conjugate* solutions. This terminology can be justified by considering the effects of an external electro-magnetic field, and it can be shown that if u_+ satisfies the wave equation with charge $+e$, then u_- satisfies it with charge $-e$.

These considerations can be generalised to a spinor field u, and the decomposition into the "real" fields v and w could be done according to

$$u = \frac{1}{\sqrt{2}}\,(v+iw)\,; \qquad u^* = \frac{C}{\sqrt{2}}\,(v-iw) \qquad \ldots \quad (16)$$

where v and w fulfil the Lorentz-invariant reality conditions

$$v^* = Cv\,; \qquad w^* = Cw \qquad \dots \quad (17)$$

The whole of the q-number theory can be worked out with the pair u, w in place of u, and the transition to the charge conjugate state is realised by $v \to v$, and $w \to w$, and for this substitution, the current vector changes its sign properly in the q-number theory quantised according to the exclusion principle. To make a transition to a neutral particle of spin 1/2, one makes an "*abbreviation*" of the theory due to Majorana by striking out w and its bracket relations or, what is the same thing, by identifying the charge conjugate states. Making this abbreviation in the q-number theory, it can be shown that the current vector , as also the magnetic moment, vanish identically. It is interesting to notice that the question so far unsettled as to whether the appropriate theory for the neutrino is the abbreviated or unabbreviated one appears to have been decided in favour of the latter alternative as a consequence of the recently established result about the non-conservation of parity in weak interactions mentioned in section 3, *i.e.* the neutrino state, and the anti-neutrino state (defined as a hole in the negative energy state) cannot be the same, and the Majorana theory for such a neutrino is, therefore, not possible. This also makes it possible to build up a theory of the neutrino in terms of two-component spinors instead of four-component spinors.

The notion of charge-conjugate states introduced above has an algebraic significance in that it can be extended to higher spins also. This can be achieved by working with field quantities called ***undors*** which form a generalisation of the Dirac spinor u_ρ, which is characterised by being a pair of spinors transforming one into the other by a space-time reflection, and are quantities $\psi_{\rho_1 \rho_2 \dots \rho_n}$ transformaing like products of Dirac spinors, the Dirac spinor u itself being considered as an under of rank one. The Majorana theory of neutral particles identifying charge-conjugate states would, therefore, deal in this case with self charge-conjugated four-spinors, or what are called ***neutrettors*** of rank one. Similarly, field functions for the case of a particle of spin 1 can be taken as the symmetric under $\psi_{\rho_1 \rho_2}$ of rank two, and this can be associated with a charge-conjugated undor according to

$$\psi^{\pounds}_{\rho_1 \rho_2} = \pounds^{(1)} \pounds^{(2)} (\psi_{\rho_1 \rho_2})^* \qquad \dots \quad (18)$$

where $\pounds$ is identical with the Pauli matrix C^*, and $\psi^{\pounds}$ is called the charge adjoint of ψ. A Majorana abbreviation would now give a ***neutrettor of rank two***, which would be appropriate as a field function for neutral particles of spin 1.

To go to higher spins, we first generalise the Pauli matrix operator by putting

$$\mathcal{L} = \prod_{\mu=1}^{n} \mathcal{L}^{(4)} \qquad \dots \quad (18,a)$$

and operate with it on the conjugate complex under $\psi^*_{\rho_1\rho_2..\rho_n}$ and derive the transformed under

$$\psi^{\mathcal{L}} = L\psi^* \qquad \dots \quad (18,b)$$

with the property that in the field equations satisfied by the $\psi^{\mathcal{L}}$, the constants of the dimensions of a charge, e, for instance, are changed into their opposites according to $e^L = -e$. Further it can be shown that the transformation

$$\psi = \psi^L \text{ together with } e \rightarrow e^L \qquad \dots \quad (A)$$

where ψ^L is given by $\psi^L = \psi^{\mathcal{L}}$ ... (B)

not only ensures the invariance of the field equations, but also the invariance of all physically significant quantities *provided that one works with a q-number theory i.e.* only taking account of the commutation rules holding between the undor components. The invariance of physical quantities under (A)—(B) is called *charge invariance*. Pauli and Belinfante have deduced the striking result that the connection between spin and statistics derived in Section 4 follows as a consequence of this postulate of charge invariance under (A)—(B), showing indirectly the partly algebraic nature of this notion.

8. PARITY, CHARGE CONJUGATION, AND TIME REVERSAL

The discovery of the host of new and strange particles, and their interactions described in Section 3 including, but still mysterious particle, the neutrino, and the proper understanding of the several conservation laws governing the interactions have necessitated a reconsideration of the algebra of elementary particles presented in sections 4–7 since the emphasis in the earlier years has been on free particles, while today the investigation of interactions between the several kinds of particles is in the centre of interest. Also questions recently raised of invariance separately under space reflections, time reversal, and space-time reflections which all constitute elements of the full Lorentz group, just like the continuous L_4, are bound to be of great algebraic significance. Although the replacement of a function by its complex conjugate is not a linear operator, we have seen in section 7 how the concept of charge invariance wherein such replacement occurs, can also be considered partly algebraic in nature. Pauli (Bohr Commemoration Volume, 1955) has recently reexamined some of these questions, and his work, coming as it did, before the discovery of non-conservation of parity in weak interactions, discusses the invariance under space-time reflections, without going into space reflections alone or time reversal alone separately. Two of his general conclusions, taking interactions properly into consideration, are: (i) for the case of integral spin, the assumption made in equation (2) that $D = 0$ if the points are separated by a space-like distance, so as to exclude the possibility of quantisation with anti-commutators, now appears superfluous, and (ii) for half integral spin, the validity of the exclusion principle, and the consequent Dirac theory of holes still holds.

He introduces the three operations viz., (a) *particle-antiparticle conjugation* (which includes charge conjugation), denoted by AC connecting every spinor field with its own complex conjugate field, also in the case of several fields, (b) simultaneous transformation of every particle into its antiparticle coupled with the reflection of space-time co-ordinates, which is called a *strong reflection*, n and denoted by SR, and (c) reflection of space-time alone without the change of particle into anti-particle which is called the *weak reflection*, and denoted by WR, and indicates the obvious result that each one of the transformations SR, AC and WR is a product of the other two. Further by considering the simplest cases of particles of spin 0, 1/2 and 1, their interactions, he has derived the following interesting results about WR, and SR :

(a) The WR transformation holds whether the normal connection between spin and statistics holds or not.

(b) The transformation law of a quantity with respect to L_4 does not determine uniquely its behaviour for WR; and the invariance with respect to WR imposes further restrictions upon the Lagrangian density of the interaction, besides the invariance for L_4.

(c) The SR is uniquely determined as a consequence of L_4, and the spin-statistics connection. The remarkable result (c) that the SR holds from more general postulates than the WR or AC is referred to as the *Pauli-Luders theorem* and throws light on some problems that have arisen in connection with the interactions between elementary particles. As SR is the product of WR and AC, it follows immediately from the above theorem that the results (a) and (b) are also true for AC with the same additional restrictions imposed on the interaction Lagrangian density, and that the transformation of a certain kind of spinor or tensor for WR uniquely determines its transformation for AC.

Although in the above considerations of Pauli, the conservation properties of space reflection, and time reversal have not been separately taken into account, it can be shown, as has been done by Lee, Oehme, and Yang (Phys. Rev., **106**, p. 340, 1957) that we can derive from (c) above, some general results regarding conservations under space reflections or parity (P), pure time reversal (T), and charge conjugation (C). Noting that SR is a combination of P, C, and T, these authors have considered the transformation properties (in the Schroedinger representation) of wave functions of the doubly quantised spin fields (both integral and half-integral) under the operations P, C and T with these transformations involving phase factors η_p, η_c, η_t of absolute values equal to unity. Working with a local Hermitian operator H invariant under L_1, they have shown that the Pauli-Luders theorem is equivalent to the statement that there always exists a choice of η_p, η_c, η_t such that (a) H commutes with the product of the operators P, C, and T taken in any order, and (b) if this choice of phase does not make H commute with P, for example, then no other choice does, and the theory is not invariant under P, and the same holds for C and T also. Of course, (b) includes the possibility also that the choice of phases made under (a) may make P commute with H. The statement (a) and (b) constitute the *CPT-theorem*, which is thus a simple consequence of the Pauli-Luders theorem. It follows from the CPT theorem that if one of the three operators P, C, and T is not conserved, at least one other must also not be conserved. Thus there are five possibilities of conservation or non-conservation of P, C, T as indicated in the table below:

No.	*Non-conserved operators*	*conserved operators*
1	...	P, C, T
2	C, T	P, CT, TC
3	P, T	C, PT, TP
4	C, P	T, CP, PC
5	P, C, T	PCT and permutations

... (19)

The CPT theorem taken along with the recently established experimental result of non-conservation of P in weak interactions, raises many interesting questions about conservation laws relating to strong and weak interactions in which the old, the new and the strange particles take part, and whether on the basis of such laws one could explain the reason for the existence of these two types of interactions separated by a wide gap. Explanation is also needed for the fact that while the number of nucleons and

total charge are conserved for all interactions, the strangeness is conserved only in strong interactions. Since strangeness is not conserved in weak interactions, the question arises as to whether there is any relation between this non-conservation, and other types of non-conservation indicated in table (19). This table also shows that the non-conservation of P in a weak interaction does not definitely decide whether C or T, or both are not conserved in the same interaction, since there are three rows in the table including non-conservation of P. Also while energy and momentum are conserved in weak interactions, the question of angular momentum being conserved is still an open one. The explanation of the invariance relation (1), and of the relationship between several K-particles, in particular, whether some of them are identical, is not yet clear. The characteristic feature of strange particles in that their production falls into the class of strong interactions, while their decay falls into the class of weak interactions, requires an explanation. It is impossible to go here into the theoretical questions involved in the numerous problems raised above, and so we will deal with a few of them only.

Considering first, the neutrino involved in the weak interaction of β-decay, the experiments of Dr. Wu and collaborators at Columbia University on β- decay of Cobalt 60 have shown that parity is not conserved in the interaction. As already mentioned in Section 7, this makes it possible to develop a two component theory of the neutrino, and it is easy to see that in such a theory, the spin of a neutrino ν^0 (defined as a particle in the positive energy state) is always parallel to its momentum, while the spin of an anti-neutrino $\bar{\nu}^0$ (defined as a hole in the $-$ve energy state) is always anti-parallel to its momentum (that of ν^0). Thus the spin and velocity of ν^0 represent the spiral motion of a right-handed screw, while the spin and velocity of $\bar{\nu}^0$ represent the spiral motion of a left-handed screw. The theory also shown that there is no invariance under C, and hence, as indicated in table (19) there may be invariance under CP, and also under T, or T also may be violated with invariance under CPT. By making a deeper analysis of the theory, Lee and Yang (Phys. Rev., 105, p.1674, 1957) have shown that the correct decay process for the μ^--meson is given by

$$\mu^- \to e^- + \nu^0 + \bar{\nu}^0. \qquad \ldots \quad (20)$$

The next question is about the status of the CPT theorem for strong interac- tions. Experimental evidence indicates that P is conserved in such actions, and it is usual to assume that C and T are also conserved, so that the first row of table (19) represents strong interactions. Making this assumptiontion, and considering a Hamiltonian $H = H_{strong} + H_{weak}$, with the former invariant under C, P, and T, and both terms invariant under L_4, one can derive some interesting results throwing light on the inter-relationships between non-conservation under C, P, and T.

The third question we will consider is the relationship between the strange K-mesons, τ^+ and θ^+, or the so-called $\tau-\theta$ puzzle. These have the decay processes

$$\left.\begin{array}{ll} & \tau^+\rightarrow\pi^++\pi^++\pi^- \\ \text{and} & \theta^+\rightarrow\pi^++\pi^0 \end{array}\right\} \qquad (21)$$

and experimental data indicate that the two particles have closely identical masses and life times. On the other hand there is evidence of the non-identity of spin-parity properties of the two particles. Both the above interactions are weak since strangeness is not conserved in them, and non-conservation of P therefore makes it possible to think of τ^+ and θ^+ as one one particle which has a definite parity on production, but which can decay into various partities. A more interesting approach to the mass degenaracy of τ^+ and θ^+ would be to assume, in analogy with the mass degeneracies of electron-positron, and neutron-proton, that an invariance law is responsible for this mass degeneracy. Assuming τ^+ and θ^+ to have the same spin but opposite parity, we can denote this invariance law as "*parity conjugation*", and denote it by C_p. Thus, C_p would commute with the part of the Hamiltonian including strong interactions (H_s) *i.e.*

$$C_pH_s-H_sC_p=0 \qquad (22)$$

The other part H_{weak} does not commute with C_p, producing the small mass difference between τ^+ and θ^+. Consider now the strong interaction

$$\pi^++n^0\rightarrow\Lambda^0+\theta^+ \qquad (23)$$

Equation (1) implies that there exists a parity-conjugated reaction of equal strength corresponding to (23) viz ;

$$\pi^++n^0\rightarrow\Lambda'^0+\tau^+ \qquad (24)$$

where Λ'^0 is the parity-conjugated hyperon of Λ^0. Extending the above reasoning to Σ, one concludes that there are two types of Σ with opposite parity. In general, it can be shown that all particles of odd strangeness S given by (1) must be *parity doublets*". For systems of even strangeness, the operation therefore leaves the parity invariant, and we have

$$C_pP-(-1)\ PC_p=0 \qquad \ldots(25)$$

SOLAR AND TERRESTRIAL RELATIONSHIPS

At the physics symposium of the last year's Science Congress (Calcutta, 1957), it was pointed out that, by noting the type of sun spot crossing at various intervals before and after the commencement of a geomagnetic storm for 1947 and 1948, some geomagnetic storms seemed to follow sunspots apparently insignificant or at the stage of getting to be insignificant and that the big spots were not necessarily be followed by notable geomagnetic storms. The active regions were tabulated in detail in connection with geomagnetically disturbed periods and cosmic ray bursts many years ago.

On Feb. 23, 1956, Kodaikanal Observatory reported a very large solar flare or chromospheric eruption at 0330 U.T. B.B.C. broadcast news and commentaries for the next few days about a phenomenal cosmic ray burst and radio fade out at the time. Dr. K. R. Ramanathan wrote to me that sharp cosmic ray increases had been recorded at his laboratories at Ahmedabad, Trivandrum and Kodaikanal. These were the first such increases at low geomagnetic latitudes. During a visit later, he showed me the records of the radio-fade out and of abnormal values of radio noise. He mentioned of a similar abnormal radio noise record of Mar. 10, 1956. The newspapers published about a very big solar flare on Feb. 10, 1956 described by Donald Menzel as many times a thermo-nuclear bomb. The Royal Observatory, Greenwich/Herstmonceux collected data from all over the world of all contemporary events. Symposia on this big flare have been held at the Royal Astronomical Society.

Among the non-periodic variations in the cosmic rays at the surface of the earth, a perceptible disturbance—a decrease in general—has, sometimes, but not always, been noted about the time of a geomagnetic storm. The cosmic ray ionization curve followed closely the corresponding geomagnetic curve on such occasions. Forbush, Stinchcomb and Schein (1950) gave the four recorded instances (Feb. 8, 1942; Mar. 7, 1942; July 25, 1946 and Nov. 19, 1949) when, corresponding to the solar flare crochets in the geomagnetic records or radio fade outs at stations on the daylight side of the earth's hemisphere, abnormally sharp increase in cosmic rays occurred.

The solar flares of Feb. 28, 1942 and of July 25, 1946 were followed within 24 to 48 hours by geomagnetic storms with closely related cosmic ray changes. The solar flares of Mar. 7, 1942 and Nov. 19, 1949 were not followed by geomagnetic storms with related cosmic ray changes.

A large number of investigations on Solar Flares, Cosmic Ray bursts even for these few events have appeared. The evolution of solar regions have not appeared prominently in them. In fact, Solar flares which have been listed of nearly equal importance in astronomical publications (I.A.U.) have been arbitrarily classified under different categories based purely on cosmic ray observations (*eg.*, Firor, 1954).

After the big solar flare of Feb. 23, 1956, the next geomagnetic storm of Feb. 25 did not show corresponding cosmic ray changes at high latitudes (Fenton, McCracken, Parsons and Trost, 1956). Sarabhai, Duggal, Razdan and Sastry (1956) have not reported any corresponding cosmic ray changes from Ahmedabad, Kodaikanal or Trivandrum all nearer the geomagnetic equator. The geomagnetic storm of Feb. 25 can be considered as indopendant of the solar flare of Feb. 23, 1956.

By assigning characteristic indices as a measure of time fluctuations of cosmic rays, it was shown (Malurkar, 1955) that though there was a general tendency for both geomagnetic and cosmic ray indices to increase together, two distinct groups existed: (a) Cosmic Ray Index high and Geomagnetic Index not quite large (Feb. and Mar., 1942); and (b) Cosmic Ray Index not quite large but Geomagnetic Index high (Mar., 1941). Similarly while during the epoch of geomagnetic storm of July 26, 1946 cosmic ray changes were pronounced, no such changes were simultaneously recorded with the very much bigger geomagnetic storm of Mar., 1946. The geomagnetic storms of Mar., 1941 and of Mar., 1946 are the two biggest ones recorded at Bombay/Alibag observatories in more than 80 years and occurred after cosmic ray observations have become routine. These two biggest geomagnetic storms along with the five solar flares listed above were looked up in relation with the progress and evolution of solar active regions. The summary table (next page) and the chief points (Malurkar 1958) are given here.

The active regions No. 7 of 1941 and No. 15 of 1946 were either short lived or showed up only a limited number of flares. Towards the end of their lives, important flares were reported. Solar flares were also reported within a day (± 1 day) of the central meridian passage of the region and within a day or two thereafter a very big geomagnetic storm occurred.

The active regions No. 12 of 1942 and No. 51 of 1946 were active from the eastern to the western limb of the sun. Large solar flares occurred when these regions were within one day (± 1 day) of the sun's central meridian. Sharp cosmic ray increases were recorded at many stations away from the geomagnetic equator. Within 24 to 48 hours, in each case a geomagnetic storm which could be correlated with cosmic ray changes at the same epoch was reported.

The active region No. 12 of 1942, No. 23 of the fourth quarter of 1949 and No. 17 of the first quarter of 1956 were all active near the western limb of the sun, i.e., within one day of it (± 1 day). No. 23 of the last quarter of 1949 had an active history extending beyond 5 to 6 days. The other two were very active for more than 11 days. At the stage of these regions nearing the western limb (± 1 day) of the sun, sharp increases in cosmic rays were observed to coincide with the time of solar flares at

TABLE

SOLAR ACTIVE REGIONS							SOLAR FLARE			DATE OF			INTERVAL BETWEEN	
Year	No.	Coordinates		C.M. Passage		No. of Distinct Observed Flares	Date	C.M. Dist.	Age	Cosmic Ray Burst	Magnetic Storm	Cosmic Ray affected? Mag. stm.	Magnetic storm and	
		ϕ	L.	Date at	Age at								Flare (in days)	C.M. Passage (in days)
1941	7	15N	354	Feb. 27.5	2	7	—	—	—	—	Mar. 1.15	No	—	1.85
1942	12	7N	197	Feb. 28.8	+26?	17	Feb. 28.5	4E	+26?	Feb. 28.5	Mar. 1.31	Yes	0.81	0.51
,,				,,		,,	Mar. 7.18	91W	+32?	Mar. 7.18	—	No	—	—
1946	15	23N	10	Mar. 26.9	>6	3	Mar. 27.2	4W	>6	—	Mar. 28.1	No	1.1	1.41
1946	51	21N	198	July 26.8	>6	37	July. 25.67	16E	>5	July 25.67	July 26.8	Yes	1.13	0.0
1949/4	23	2S	116	Nov. 14.1	3	17	Nov. 19.40	75W	8	Nov. 19.44	—	No	—	—
1956/1	17	22N	176	Feb. 17.8	>6	32	Feb. 23.13	80W	11	Feb. 23.13	—	No	—	—

[*Note* : (a) C.M. distances and age refer to those of the solar active region numbered in each row.
(b) C.M. distances approximate within a few degrees only.
(c) For No. 23 of fourth quarter 1949 active region, the age at C.M. Passage is given as −1 in Q.Bull. of I.A.U. It was however observed at Mitaka on Nov. 11, at Kanzelhohe on the 13th and again at Mitaka on the 14th and the age has been changed here accordingly. It is mentioned that this active region was a fresh formation on the return of active region No. 13 of the fourth quarter of 1949].
Solar Data from Quart. Bull. Solar Activity. Int. Astro. U., Zurich.

many stations. On Feb. 23, 1956, it was recorded even near the geomagnetic equator. On Feb. 10, 1956 when the region No. 17 of the first quarter of 1956 was at the *eastern limb* and gave a very large flare no cosmic ray abnormality has yet been reported.

Assuming that the above have more than particular application, it follows that large cosmic ray bursts have occurred in connection with solar flares associated with active regions with long history of considerable activity when either the active region was near the central meridian or near the western limb of the sun. When it occurred near the C.M. of the sun, a geomagnetic storm coupled with corresponding cosmic ray changes followed. When the region was near the western limb of the sun, no such closely associated geomagnetic and cosmic ray disturbances followed the big solar flares and sharp increase in cosmic rays.

The purely very big geomagnetic storms followed the C.M. passage of active regions whose history of activity was less marked. Either it had begun only a few days earlier or its activity was relatively less. At the stage of dissolution of the active regions soon after the C.M. passage, flares of importance 3 followed by big geomagnetic storms happened.

The time interval between the C.M. passage of the active region and the geomagnetic storm was less when it followed a large cosmic ray increase solar flare than in the purely geomagnetic storm. Even the time interval between the solar flare and the subsequent geomagnetic storm is less. The particles for a cosmic ray geomagnetic disturbance have greater velocity than those for purely magnetic storms.

As the cosmic ray bursts are associated with solar active regions of long history and of abnormally large chromospheric activity, the particles responsible for cosmic ray changes can be assumed to have been accelerated over many days in those regions. The particles emitted near the sun's C.M. would be normal to its surface while those from the limbs can be expected to be tangential to it. The purely cosmic ray bursts (i.e., unrelated to a subsequent geomagnetic storm) happened when the active region was near the western limb. Even though at the eastern limb, the same region showed great activity (perhaps greater activity than when at the western limb) no cosmic ray burst has been reported. The particles must have same definite polarity or charge. The particler responsible for cosmic ray bursts when the active region is near the C.M. of the sun might also be charged.

As the particles have to retain identity at the stage of acceleration for many days in the sun's active regions before being emitted into space, the particles or atoms should neither be on the side of low nor of high atomic numbers. The frequency of solar flare-cum-great cosmic ray bursts has been small. The element involved would be less abundant than the usually emitted ones. If group II elements are considered, one will have to look for Strontium or Barium atoms which constitute only 0.03 per cent of the Calcium content in the sun. It would therefore be necessary to look for these or for other unusual elements in the spectra of the very large solar flares which have given sharp cosmic ray bursts.

The same methods of looking into primary data and of re-examining basic assumptions afresh have been adopted in other branches, given here.

STABILITY OF TOP HEAVY LAYERS

Soon after I joined the India Meteorological Department, I noticed that Napier Shaw had stated in his Manual of Meteorology that lapse rates in inferior mirages had not been measured. The Ganeshkhind Road near the Meteorological Office at Poona had been newly asphalted and was showing inferior mirages on sunny afternoons. When I mentioned these to Dr. L. A. Ramdas who had also just come to Poona, he quickly enquired why we should not measure them. We took for a few hot afternoons the dry and wet bulb temperatures very near the ground. The rate of fall of temperature from the ground was much steeper than ordinarily allowed. The nature of fall of temperature with height also did not conform to the expected exponential ones. Mistakes of 0.3° to 0.5° C. could not have been committed. The temperature fall in the curve was much steeper at every stage. Above a few feet, the rate of fall was relatively negligible. The next attempt was to fit a curve to the observation, to get its approximate differential equation and to bring in facts that could supply such an equation. The shape of the curve of high lapse rates near heated ground and later near hot plates was explained on the basis of usual eddy diffusion (viscous eddies) combined with radiation from and into successive thin layers of air due to watervapour content (Malurkar and Ramdas, 1931). The theory was developed to higher layers of the atmosphere with varying temperature and humidity to give a relation of temperature kinks at surfaces of humidity discontinuity (Malurkar, 1932), to explain the temperature fall very near the ground even when higher up a temperature inversion existed on the basis of micro-eddies and finally to derive an approximation for the nocturnal radiation and giving a logical basis for the various formulae used till then (Angstrom's Boutaric, Brunt), [Malurkar, 1936]. But the main problem of abnormally large lapse rates near the ground, which was one of stability of layers of fluid when heated from below, remained. Aichi (1907), Rayleigh (1916), Jeffreys (1928) and Low (1929) had given criteria which had been far exceeded. The assumption of a uniform change of temperature with height was not borne out by observations, and needed looking into. For simplicity, the problem was split into two parts (a) nature of the temperature height curve and (b) maximum temperature difference that could be maintained for top heaviness to lead into instability in fluid layers with that temperature—height curve.

For a rectangular system of coordinates, x, y, z with z axis measured upwards; u, v, w as component velocities, ρ the density, p the pressure, and ν the kinematic viscosity and k the coefficient of eddy viscosity, the fundamental dynamical equations are :

$$\rho d(u, v, w)/dt - \nu\rho\Delta(u,v,w) = -(\partial/\partial x, \partial/\partial y, \partial/\partial z)p - (0, 0, g\rho) \quad \ldots \quad (1)$$

where Δ represents

$$\partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$$

$$d\rho/\rho dt + div(u, v, w) = 0 \quad \ldots \quad (2)$$

and

$$\rho c_p.d\phi/dt = k\Delta\phi - (\partial/\partial x + \partial/\partial y + \partial/\partial z).E \quad \ldots \quad (3)$$

where E is the radiation that crosses a unit layer at xyz and ϕ is the temperature excess at xyz over a certain definite temperature and c_p is specific heat at constant pressure. If the total variation of temperature in the whole layer is small compared with the absolute magnitude, Eqn. (3) can be written to a very great approximation as

$$\rho c_p d\phi/dt = k(\Delta\phi - \alpha^2\phi) \quad \ldots \quad (4)$$

From a purely mathematical point of view, it is immaterial how the term $-\alpha^2\phi$ enters. It may be due to radiation or may be a purely empirically added term. If the variations of pressure in the layer are small, the equation of density can be written as

$$\rho(\theta_0 + \phi) = \rho_0\theta_0 \quad \ldots \quad (5)$$

where θ_0 is the definite temperature and ρ_0 the corresponding density. These refer essentially to thin layers of the atmosphere or gas above a heated plate. Taking account of steady conditions, and neglecting products of departures from the steady values, replacing d/dt by the corresponding approximation $\partial/\partial t$ and some algebraical simplifications we get

$$\Delta[\Delta - \partial/\nu\partial t] \left\{ \frac{1}{\partial\phi/\partial z} \left(\Delta - \alpha^2 - \rho c_p \partial/k\partial t \right) \phi \right\} + \frac{g\rho c_p}{k\nu\theta_0} \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) \phi$$

$$\frac{1}{\theta_0} (\Delta - \partial/\nu\partial t)(\Delta - \alpha^2)\partial\phi/\partial z \quad \ldots \quad (6)$$

For this investigation the right hand side is negligible. When instability is about to start $\partial/\partial t = 0$ and

$$\Delta^2 \left\{ \frac{1}{\partial\phi/\partial z} \left(\Delta - \alpha^2 \right) \phi \right\} + \frac{g\rho c_p}{kv\theta_0} \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) \phi = 0 \quad \ldots \quad (7)$$

putting $\phi = \phi_i + \phi^1$ where subscript i denotes steady values and

$$\frac{\partial^2\phi_i}{\partial x^2} = \frac{\partial^2\phi_i}{\partial y^2} = 0 \; ; \frac{\partial^2\phi_i}{\partial z^2} = \alpha^2\phi_1 \quad \text{and} \quad \phi^1 = \chi\epsilon^{i(x+my)}$$

it follows that

$$(d^2/dz^2 - l^2 - m^2)^2 \left\{ \frac{1}{d\phi_i/dz} \left(d^2/dz^2 - l^2 - m^2 - \alpha^2 \right) \chi \right\} = \frac{g\rho c_p}{kv\theta_0} \left(l^2 + m^2 \right) \chi \quad \ldots \quad (8)$$

with actual temperature distribution

$\phi_i = \beta h \dfrac{\sinh \alpha(h-z)}{\sinh \alpha h}$; β is mean lapse-rate in the height interval h

where h is the thickness of the layer, α and β are constants and

$$z = h(\pi - \xi)/\pi, \qquad \gamma = h\alpha/\pi, \qquad a^2 = h^2(l^2 + m^2)/\pi^2$$

$$b^2 = h^2(l^2 + m^2 + \alpha^2)/\pi^2$$

it follows that when $0 < \xi < \pi$ and

$\lambda = \beta g\rho\, c_p h^4/\pi^4 kv\theta_0$ the main equation of the problem

$$(d^2/d\,\xi^2 - a^2)^2 \operatorname{sech} \gamma\xi \,.(d^2/d\,\xi^2 - b^2)\chi = -\lambda a^2 \pi\gamma \operatorname{cosech} \pi\lambda.\chi \quad \ldots \quad (9)$$

Digressing a bit : This equation is not readily solvable by the usual methods. The method used by Low and Jeffreys are too restricted.

The mathematical side was formulated as $f(D)y + Iy = 0$ where $D = .d/dx$ and I is a function of x only, or more generally $f_1(D)y + f_2(D)y = 0$ where f_1 and f_2 are polynomials in D and the order of polynomial in f_1 is greater than in f_2. A direct substitution of fourier series or linear combinations of orthogonal functions leads to an unintelligible result (Jeffreys, 1928). But a slight modification leads to a workable result. Assuming that

$$y = \tfrac{1}{2} A_0 + \Sigma(A_n \cos nx + B_n \sin nx)$$

the differential equation may be solved in the modified form

$$f_1(D)y = -f_2(D).[\tfrac{1}{2}A_0+\Sigma(A_n \cos nx+B_n \sin nx)$$

$$= \tfrac{1}{2}\, L_0+\Sigma(L_n \cos nx+M_n \sin nx)$$

Let the general solution of $f_1(D)y = 0$ be Y. The solution of the modified equation $Y+P(x)$. Comparing the fourier coefficients of $Y+P(x)$ with the resultant fourier coefficients of L's and M's, the complete solution can be got, in most cases.

Instead of the Fourier set, a complete set of orthogonal set of functions can be used in the series but then the form of f_1 and f_2 would not be mere polynomials. This method was sent for publication in 1936 (Malurkar, 1937*a*). This method has also recently been published in extenso (independently) by G. E. Backus (1955), for use of stability problems which have come into prominence for their applications.

Returning now to the main problem, the equation was solved for Rayleigh and Jeffreys boundary conditions by some heavy mathematical work and use of solid determinants.

With Rayleigh condition the stability limit was given by

$$\beta g\rho c_p h^4/\pi^4 kv\theta = \lambda = \frac{(1+a^2)^3}{a^2}\left[1+ \frac{(5+a^2)\gamma^2}{4(1+a^2)}\right]$$

Compared with Rayleigh's assumption of constant lapse rate when $a^2 = 1/2$, the above limiting value of maximum lapse-rate before instability sets in in the top heavy layers value is larger even in the first approximation. A similar result holds good for Jeffrey's boundary condition.

It followed that the degree of top heaviness was increased before instability could set in when the temperature height curve was concave upwards instead of being a straight line (Malurkar, 1937*b*). Applying to the atmosphere, the actual temperature difference that can be found without instability between two levels of the atmosphere is greater or less than that found by Hales (adiabatic dry one) if the temperature-height curve is concave upward or concave downwards than if a linear temperature height curve existed (Malurkar, 1939).

In 1932–34 a study of thunderstorms using sounding balloon data was undertaken to verify whether potentially colder air is superincumbent on warmer air as given in studies in the India Met. Department where only surface meteorological data and ordinary pilot balloon winds had been used. The sounding balloon data did not show any instance of such inherently unstable superposition when thunderstorms occurred near Poona or dust-storms near Agra. In the thermodynamic diagrams published till then, in the department, a rising air mass was taken just to the level of its static equilibrium and was hardly considered as a dynamic system when it would shoot past to its dynamical level of equilibrium. The problem was again split up into (a) favourable conditions to maintain convection or thunderstorms, (b) initial causes of upward convection and (c) difference introduced by considering the dynamical level of equilibrium instead of the statical one for a rising mass of air. The sounding balloon records had shown that on days when thunderstorms occurred in the neighbourhood, the air at higher levels 2 to 4 kms was potentially colder than the corresponding air at the same levels on earlier days instead of being colder than layers below; this would allow convection once started to be easier maintained. The air at lower levels might sometimes be potentially warmer than the air on earlier days at the same levels. This would help further the maintenance of convection once started. The causes of initial convection were : strong *unequal* surface heating, non-horizontality of surfaces of equal humidity with sufficient gradient of humidity or mixing ratio, large waves at the separation of two air masses and gradient wind velocity due either to orography or to juxtaposition of two air masses with different horizontal velocities. The additional height to which a rising air mass would go above its statical level of equilibrium where it condenses easier was a vital factor to be considered. The paper was read at Poona in 1934 and due to my transfer to Agra was sent completed for publication early in 1936. It did not see the light of day in time. Due to some other necessity, I was allowed to publish the non-forecasting theoretical part only (due to war secrecy) in 1943 (Malurkar, 1943*b*). The forecasting or applicational side was published in 1949 (Malurkar, 1949*b*). Thunderstorms in the tropics and subtropics were treated same way everywhere.

TROPICAL METEOROLOGY

I was put on actual weather forecasting from 1938–42 at Karachi and again, in spite of my own preference, at Poona from 1942-45. Looking back, the period-mostly war time with its restrictions, non-availability of trained staff even for the daily routine, non-availability of familiar data, radio-silence and receipt of data which had not been in use in the department for over thirty five years—all reminded me about the thickly grown tropical forests mentioned earlier. Perhaps the situation was inevitable.

After 1905, slowly the reference to and the plotting of observations in S. W. Indian Ocean had somehow gradually diminished in the Indian Daily and other periodical weather publications. It would be hardly scientific to assign this diminution as a recognition of a superfluity and to claim that the results deduced with subsequent regular observations in the S. Indian Ocean were obvious or well-established. Current ideas do and must find expression in publications, specially from that area. Wagner (1931), Sur (1932), Ramanathan and Ramakrishnan (1932) hardly mention meteorological conditions or observations in S. Indian Ocean. Ramanathan and Ramakrishnan (1938 reprint 1943) were sceptical of the role of even "southerly air" not to mention air from the southern hemisphere for the pre-monsoon, cyclonic storms in the N. Indian Seas. A study of the monthly mean upper winds only in the north of the equator could not be expected to give clear enough indications of short-period discontinuous incursions of fresh monsoon air from south of the equator to the north. If, on the other hand, one had working experience of daily charts, then the mean monthly charts over both sides of the equator could be made to yield some results (I have tried it for equatorial oceanography). Mere mention of some terms in a vague way does not prevent the same ones being used with specific connotation. The use of the word "pulses" of monsoon is not a rehash of the old 'pulsating current.'

At Karachi, as a novice, it was difficult to comprehend the disjointed and *ad hoc* explanations I got for many weather phenomena. The picture that I could have had when I left the place was none too satisfactory. The extent of the Karachi chart was grossly inadequate for the S. W. monsoon with hardly one or two observations on the west coast of India. Even observations from Iraq, an area adjacent to the limit of its forecasting responsibility, became scanty (1940–42). Forecasting with very inadequate basic data had perforce to be attempted. At Poona, the Indian chart, though it lacked observations from ships, from Burma and from further east, was a big morsel. Considering its responsibilities and the past experience at the place, it was handicapped. Observations from U.S.S.R. in Asia were also plotted. There was hardly time to collect statistics or climatology. *Ad hoc* methods were out of place.

Soon after the Contai (Midnapore) cyclonic storm in Oct. 1942, when I had singly to look after the weather charts, Poona Meteorological office located a depression in the Bay of Bengal. For the next few days, Port warning work for the Bay of Bengal region was done by Poona. After the first two or three days, the coastal surface and upper winds also looked weak and gave little direct indication of a depression in the Bay. Based on the coastal observations, sequence of weather, isopleths were drawn as a non-intersecting family of curves. The depres sion was followed to the day of its crossing (within fifty to hundred miles all the way). While the method succeeded in the particular instance, the point arose whether it could bear extension. Physically there was no reason to the contrary. I put forward a few ideas later in a lecture on the "Basis of Tropical Meteorology". Soon I was asked to prepare in a few weeks a manuscript on forecasting weather over India in all its aspects. My own collection did not include all topics. Only a logical basis of deduction, verification at crucial stages (once or at most twice for each phenomenon) and mixing of cause and effect (by process of analysis) could replace wide experience and climatic and statistical information.

The observations from the S. Indian Ocean including a few just south of the equator began to be plotted as a routine from May, 1943. Those from W. Asia and N. E. Africa also were used. As the receipt was through radio-broadcast, some observations were inevitably missed on many days. Forecasting methods with inadequate data proved helpful. The stimulating discussions I used to have almost daily with Rao Bahadur M. G. Subramanyam were of considerable advantage in clearing my own ideas. He could talk of very old days.

The surface gradients of measured elements in the tropics are smaller than in higher latitudes. If air mass or stream analysis had to be made, the tracing in space and in time had to be enlarged. Sequence of phenomena was an important guide.

A definite method of approach, though it may not be possible to express it in algebraical symbols, was a step forward. Any theory formulated or any picture must comprehend as many of the known facts as possible without an overloading of *ad hoc* assumptions for each type of event and must lead to fresh verifiable results. While every stage of argument may not be directly demonstrable, definite contradictions could not be allowed. The whole picture grew out of current ideas which had been published or from experience indicated during discussions with others, as a basis. The continuous in-feed of new data on these brought in inevitable modifications and the growing needs of the clientele acted as an incentive.

The Indian rain is during the periods of S. W. monsoon, of N. E. monsoon, of the post- and pre-monsoon depressions in the neighbouring seas, of the western or winter disturbances in N. India and of sporadic thunderstorms. For the S. W. monsoon and for the pre- and post-monsoon depressions air from south of the equator is an important constituent. Fresh maritime air crosses or *tips over* the equator at intervals of a few days depending on specific conditions. In the S. Indian Ocean over a belt near the equator, the pressure gradient during the northern summer is *on an average* absent or negligible. But on any individual day it is not so. Shallow low pressure areas called "pulses" travel W or WNW wards just south of the equator in the Indian Ocean carrying fresh maritime air, at intervals of every few days. If across the path of, and to the south of these shallow low pressure areas or "pulses" high pressure regions develop more than usual, they can cross over to the N. Indian Ocean. This fresh maritime air on crossing the equator could be described as Eq. Maritime air Em and would be carried along and feed into a monsoon depression or cyclonic storms of the pre- and post-monsoon periods. All along its way from the equator to the point of depression, it produced thunderstorms. Its energy is easily releasable. The diurnal variation in its mass is hardly 1 to 2° C. and its temperature at sea level is about 25°C.

The next air stream which was traced from *outside Indian borders* was the Far Eastern Transitional or Mixed air: Roy and Roy's (1930) 'deflected and desiccated monsoon air' was not applicable to all depressions. The potential wet bulb temperature of this air was greater than that of the fresh monsoon air that the idea of desiccation is not valid. The particular configuration at the head of the Bay of Bengal responsible for deflecting did not exist elsewhere. This is an air stream from the same side of the equator as the depression with characters depending on the season and on the locality with ultimate origin in the high pressure area of the N. Pacific Ocean. It flows along the N. E. Trades in winter and with the displaced N. E. Trades in summer (displaced because of the vast low pressure area over Asia). Part of the air has equator-ward motion and exhibits mid-air inversions. Though it is hotter (potential wet bulb temperature is also hotter) than the Eq. Maritime air, it does not release energy easily. When this air is near the equator 'pulses' of low pressure area can be found and when it crosses the equator to the other side it becomes the Eq. Maritime air there. Its role (Malurkar, 1948) is neither a source nor a sink but it delays the release of energy of the Eq. Maritime air till vorticity is built up in a tropical depression.

The third air mass is dry land air with less humidity, large diurnal variations of temperature on the ground and brings in unusually hot or unusually cold days over the region where it passes. It acts as a sink mass. For Indian area this air is from W. and N. Asia.

With an extensive weather chart, the various air streams can be separated and studied. With an interchange of N. to S. and *vice versa* the ideas can be transferred to the weather in S. Indian Ocean. The Indian weather is not a closed box outside the tropical general phenomena. But this could be realised and applied to actual work for fresh ideas only with the large charts which started in May, 1943.

Earlier to the formation of and further away from a tropical or monsoon depression, between every two infeeding streams there is stagnant air which can at best be described as '*mixed*'. In the larger field of circulation of the depression, there would be precipitation in this *mixed* stream whenever convergence of one or other types occur. It is possible to mistake this "mixed" air as the main monsoon stream and follow it to very different sources. An example can be found near the west coast of India. Before the Bay of Bengal monsoon depression, the path of thunderstorms and of Em is from S. E. Madras to Orissa coast. With the formation of a monsoon depression at the head of the Bay, places along west coast and even Poona get continuous rain. The rain stops equally suddenly when the monsoon depression in the Bay crosses coast. The rain along the west coast has to be explained by dynamics of the larger field of the depression (Malurkar, 1948) as it does not precede in time sequence the formation of the depression. The type of rain of a depression in N. E. angle of the Arabian Sea has more of a creep along the coast and produces more thunderstorms.

In the period of the S. W. monsoon, if the 'pulses' from south of the equator did not cross to the north either to the Bay of Bengal or E. Arabian Sea but moved away westwards, the monsoon over the country was weak or there was a "break". But when it did cross the equator the Indian monsoon increased. When the Far Eastern air did not feed into the field, depressions as such were not formed, but low pressure areas moved away with a not too good distribution of rain over the country.

When a monsoon 'pulse' fed into a depression it had a westerly movement. When the depression moved away from the equator, then the chance of 'pulses' reaching it becomes less and it would also be getting into the field of westerlies. The motion of the depression would get an eastward component. As depressions were guided by high level winds in the source sector (Malurkar, 1947*a*), a rigorous convention of a tropical cyclonic storm only when air from all three streams is recognisable and where the depression has an essentially westward component of motion (Malurkar, 1948), was suggested. Western disturbances move in the field of westerlies. By noting the position over Iraq, even in the absence of observations north of India, there would be a chance of indicating a tendency for recurvature of more southerly westward moving monsoon or non-monsoon depression and for forecasting rain after a definite time lapse over the W. Himalayas (Malurkar, 1943*a*, 1945, 1950).

The western disturbances were split up into distinct separate circulations (secondaries) with independent evolutions and almost ENE paths for each. The resulting weather is a sum total from all the secondaries. The strength of westerly winds decreases at the same level and the change-over occurs at a higher level as equator is approached. Each secondary low pressure area of a western disturbance travels slower and extends vertically to a lesser height than its immediate northern primary. In winter, when a tropical cyclonic storm moving westwards was south of the equator, the western disturbances in about the same longitude range gave little precipitation over N.-W. India. The Far Eastern air at low latitudes north of the equator fed into the southern cyclonic storm and intensified anticyclonic cells in the N. Indian area and produced drier weather. If on the other hand, the southern cyclonic storm filled up or recurved, the Far Eastern air north of the equator fed into the western disturbance and made it very much more active (Malurkar, 1943*a*, 1945, 1947*b*, 1950). These two results on western disturbances could only be deduced from observations over the whole of Indian Peninsula including extreme S. India, Ceylon and the neighbouring seas along with S. Indian Ocean observations and the definite mode of approach.

Another parallel very important deduction of the observations and of the methods was that two tropical depressions, one on either side of the equator, both moving in a westward direction could not for long co-exist when the longitudinal separation was small about 10°. This includes four possibilities: (a) both the tropical depressions may fill up, (b) one of them may fill up and the other can pursue its westward journey, (c) one tropical depression may recurve under the influence of an extra-tropical disturbance and the other may continue on its westward journey and (d) both the tropical depressions may recurve after they have moved away from the equator under the influence of extra-tropical depressions or their secondaries. Examples to illustrate each of them were available (Malurkar, 1950). The last two could only be derived because of the convention mentioned earlier of tropical depressions.

The effect of tropical depressions south of the equator on a northern cyclonic storm, drying of the western disturbance and the 'break' in the monsoon when a 'pulse' or closed low pressure area travels westwards all can be combined that when a cyclonic storm is moving westwards in the S. Indian Ocean, the tendency is for a large part of India to experience dry weather outside the belt 10° to 12° of the equator and within a longitudinal sector of 15° to 20°.

More popular conclusions would be partial explanations of "Why is a major portion of India dry in winter?", of "Why is Australia drier than India?" and of the distribution of Arid Zones on either side of the equator. The path of the sub-tropical western disturbances and the favoured positions of secondaries also indicate the run of arid zones. It looks that it would be necessary to afforest the area of the more equator -ward secondary before tackling with a more northerly or pole -ward one to keep up the moisture in the lower layers and to increase the vegetation.

While the concept of S. E. Trades crossing the equator to become S. W. monsoon over India was available in the first few decades, the observations were confined to the S. W. Indian Ocean. After the significant correlation with S. American high pressure area became known, the path of air travel to the S. Indian Ocean was taken from west to east along the roaring forties and then up into Indian Ocean. But there is a belt of high pressure between India and the roaring forties of the S. Hemisphere which acts as a barrier. On the other hand, if air is supposed to move from the northern side of the S. American high westwards, there is a corridor of low pressure where the Trades blow all the way to Indian Ocean. The further crossing can take place easily as mentioned earlier. This approach gave a physical meaning to many of the factors which had or have been used for seasonal forecasting of the S. W. monsoon rain over India (Malurkar, 1945, 1950).

Reverting to thunderstorms in the tropics, in the 'heat' type, there is no fall in wet bulb temperature after a thunderstorm while in 'frontal' type like Nor'westers in Bengal there is an appreciable fall in the wet bulb temperature. With the help of analysed western disturbances where the secondary travels slower and extends to a lower vertical height than its northern primary, a simple explanation of fall in wet bulb temperature without invoking descent of air from 4 to 6 kms was given. The same analysis showed how at higher levels potentially colder air than what was existing at the same level earlier and potentially warmer and more moist air than what was existing at the same or corresponding lower level earlier could give favourable conditions for thunderstorms. These 'frontal' thunderstorms following the western disturbances or their secondaries occur on the northern side of the high pressure belt which circles round the sub-tropics at 2 to 4 kms. Due to the anticyclonic cells, the induced circulation on the northern side of the high anticyclonic cells brings in fresh air to the southern side of the anticyclonic cells, and the air at these levels would be potentially colder than those at the same layers earlier. The more southerly regions are moist and warm also. Even to the south of the cells, conditions become favourable for thunderstorms. Here south of the high pressure belt, as there is no secondary western disturbance with its cold sector, the thunderstorm is not accompanied by fall in wet bulb temperature i.e., a 'heat' thunderstorm alone is met with (Malurkar, 1949*b*). As the assumptions were general, the same criteria would hold good everywhere in the sub-tropics of the northern hemisphere and by changing south to north and *vice versa* could be transferred to the southern hemisphere. Applications were made to 'Burma and Siam'. The thunderstorms of Tenasserim and of lower Burma were heat thunderstorms while those in U. Burma and N. Siam (Thailand) were in winter 'frontal'. "As a rule, 'heat' thunderstorms should occur in C. America and S. Mexico. In the more northern places, in, winter and spring (early summer) 'frontal' thunderstorms must be the rule. "... The extra-tropical depressions or their diffuse secondaries over the (lower Missisippi) valley should give rise to severe thunderstorms. Just as in India where 'tornadoes' occur sometimes in Bengal, the valley is also subject to the visitation of 'tornadoes'... ...tornadoes occur in association with 'frontal' thunderstorms which should occur on the poleward side of the upper air high pressure belt."

The other concomitant factors attendant with weather happenings have also been discussed so that Indian weather forecasting could use observations over a wide area from May 1943 by examining facts once again.

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SECTION OF CHEMISTRY

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STABILITY OF LYOPHOBIC COLLOIDS

It is my first duty to offer my thanks to the Indian Science Congress Association, for the honour done to me by asking me to preside over the deliberations of the Chemistry Section this year. I am conscious of my limitations, but I hope that with your cooperation and help, I shall be able to carry out the work entrusted to me.

Higher study of Chemistry in the country may be said to have been initiated from two places Calcutta and Madras. It was in 1875 that the Presidency Colleges at Calcutta and Madras appointed professors of Chemistry, Professor Alexander Pedlar and Professor W. H. Wilson respectively. The former was a student of the Royal College of Science, London, and the latter had his training at Prof. Bunsen's Laboratory at Heidelberg. Both these professors brought with them the traditions of teaching of inorganic chemistry. It will always be remembered that late Acharya Prafulla Chandra Rây at Calcutta did the pioneering service for the progress of chemical research in India. Most of the British professors, who came later were specialists in organic chemistry and they pursued higher study and research in this branch, in the universities or research institutes to which they were attached. The promotion of study and research in physical chemistry was mainly due to the efforts of a number of young men inspired in research by Acharya Rây. Some of these brilliant young men also went abroad and took up on their return teaching and research in physical chemistry at the various Indian universities. Among them may be mentioned the names of Professors N. R. Dhar (Allahabad), J. C. Ghosh (Dacca and Bangalore), J. N. Mukerji (Calcutta and New Delhi) and also late Sir S. S. Bhatnagar (Banaras and Lahore). Thus in the first quarter of this century flourishing schools of research in physical chemistry were established at various places, and one will be struck by the fact that the branch of Colloid Chemistry received the attention of most of these workers. The school at the University of Allahabad made important contributions to the stability of colloids and adsorption, while work on the stability of colloids specially with respect to zeta potential was developed at Calcutta. The study of gel structure and emulsions was pursued at Banaras. Since then, a large amount of contribution has been made by the Indian physical chemists on colloidal systems, and it is gratifying to find that there is hardly any research centre in this country, where work on this branch of physical chemistry is not in progress. The present speaker has been associated since 1923, with the work in colloid chemistry at the University of Allahabad. He had the good fortune to learn the fundamentals of research from Professor N. R. Dhar, a great teacher and a chemist with exceptional devotion to research. I shall now present one of the important problems of Colloid Chemistry, viz., Stability of colloids, a subject in which I and my coworkers have been interested for more than a quarter of century.

STABILITY OF LYOPHOBIC COLLOIDS

INTRODUCTION

A fundamental problem of colloid science is the stability of the colloidal particles and the knowledge of the factors which determine it. This cannot be treated without considering the existence of two types of colloids, the reversible or lyophilic and the irreversible or lyophobic. Classical examples of the former type are the proteins, soaps etc., while among the latter type may be cited the gold sol. The behaviour of the reversible colloids is characterised by their high stability and their interfacial tension which is nearly zero[111]. This leads to their instantaneous dispersion in the surrounding medium and thus an equillibrium of the size distribution of the particles results. The lyophobic colloids, on the other hand, are thermodynamically unstable possessing inherent tendency to grow, which may be prevented by the barrier arising out of the electric charge which they carry. The repulsive force, when it is small, may be overcome by the attractive force, so that on mutual approach of the colloidal particles due to their Brownian Movement, they coalesce and form bigger units.

The stability of macromolecular colloids prepared by organic synthesis appear to be entirely due to the interaction of the medium. Thus monostyrene is miscible with benzene and macromolecular polymers of this substance remain to some extent soluble in the solvent. Similarly, a large number of dyestuffs possessing colloidal properties have a definite solubility in a solvent and are highly stable. Several years ago, Ghosh and Dhar and their coworkers[3, 37] studied the colloidal properties of such acids as, molybdic, tungstic, vanadic and antimonic. They have shown that these polyacids, when freshly prepared are soluble in water and their sols are highly stable. If they are allowed to age, they have a tendency to aggregate forming bigger units, and gradually lose their solubility in water. With increasing aggregation on ageing, these colloids become unstable and behave like lyophobic sols.

SOLVATION AND STABILITY

Some older investigators have attributed the stability of lyophobic sols to high solvation of dispersed particles. Ghosh and Dhar[39] pointed out that high solvation of some sols is only one of the several factors controlling the stability. Numerous colloids, as those of hydrous oxides of vanadium, cerium and thorium, and phosphates, arsenates, borates of iron, chromium etc., show the evidence of high solvation, yet in their stability they are similar to lyophobic sols. If the surface carries a layer of the solvent, the coalscence linking across the layer of the medium is likely to be weak.[93] Aggregation requires the absence of such adsorbed layer of solvent, and it occurs in the least lyophilic region on colloidal surface. If, therefore, a colloid particle carries a layer of the solvent partially covering the surface, it may behave as a lyophobic colloid in its stability. It may be capable also of yielding gel, a common property recognised for lyophilic sols.

The amount of the solvent associated with a colloid is difficult to estimate. Generally, the rheological property of a sol is said to be associated with the solvation of a colloid. Lyophilic sols are highly viscous and do not obey Einstein's linear relationship between viscosity and concentration. Various expressions between viscosity and concentration of lyophilic sols have been suggested by different investigators, and some of these have been used to measure the extent of solvation of colloid particles. The solvation measured in most cases is an approximate estimate and sometimes the values obtained are absurd. Thus, Ghosh and Banerji[36] showed that the degree of hydration of gelatine and that of agar sols decreases on increasing the dilution. Ghosh and coworkers[40] have also reported that the sols of ferric phosphate, ferric arsenate etc., on dialysis become less stable, but show considerable increase in viscosity. It appears, therefore, that these sols become more hydrated on dialysis, but less stable towards electrolytes. Similarly, Freundlich and Ishizaka[25] showed that the rate of flow of a sol of hydrous aluminium oxide decreases on the addition of an electrolyte. In other words, as the sol approaches the stage of coagulation, the viscosity goes on increasing. Such observations are common and hence Dhar and coworkers[11] concluded that as the electric charge on the colloidal surface is gradually removed, it gets more and more solvated. From these investigations we may conclude that either solvation plays an insignificant role towards the stability of a sol, or the measurement of rate of flow, i.e., the viscosity, does not provide a correct measure for the solvation.

Garrett[32] showed that highly viscous sol as that of gelatine can withstand a shearing force and does not behave as a Newtonian fluid. Since then numerous workers have come to similar conclusion and Wo. Ostwald[84] described such behaviour as 'Structural flow'. A considerable amount of work in this direction has been published from our laboratories[98a] A modified form of Hosking's apparatus using Ostwald's viscometer has been designed, where the rate of flow through a capillary can be measured at variable pressures. It has been shown with several sols, which are viscous and yield gels, that the viscosity coefficients decrease with increasing rates of shear and the sols develop pseudoplastic phenomenon. Further, we have shown that when the rate of flow is measured at higher pressures in the absence of turbulent flow, viscous sols have a tendency to obey Einstein's linear relation. In other words, we have been able to establish that the so called high viscosity of several sols, capable of giving gels is due to the development of a loose structure. The smaller rate of flow may be ascribed mostly to the pseudoplastic property of sols in addition to the high solvation of colloid particles.

THE ELECTRIC CHARGE ON COLLOID PARTICLES

The electric charge on a colloid particle has been recognised to be important in determining the stability of lyophobic sols. The large surface of the dispersed material provides sufficient free energy, which tends to decrease by its aggregation. It is, however, prevented by the repulsion due to the electric charge on the colloidal particles. Hardy,[54] established from cataphoretic experiments that stability of sols is due to the electric charge arising out of the adsorption of ions. Duclaux,[23] Malfitano and others,[72] ascribed the electric charge to the dissociation of the colloidal unit like an electrolyte. Pauli[87] advanced the view that the colloid particles are complex ions obtained from the compounds of Werner type. Löttermoser and coworker,[71] emphasised the origin of the charge on the colloidal particles to the preferential adsorption of ions from the peptising electrolyte present in the system. Such peptising electrolyte in most cases, either contains a common ion constituting the precipitate, or an ion capable of being highly adsorbed, or even capable of chemically interacting with the solid dispersed. Thus, silver halides can be peptised either with silver or halide ions, and a number of basic hydrous oxides can be peptised by traces of acids. Ghosh and coworkers [18, 41] have emphasised that in several cases, the electrolyte capable of forming complex salt with the insoluble substance, acts as a good peptising agent. A number of instances are also known, where colloidal solutions are obtained in the presence of polyvalent ions. In short, the peptising capacity of an electrolyte is highly specific in nature.

The electric charge on the colloidal surface is balanced by an equivalent amount of the counter ions forming a double layer. The structure of this double layer has been considered by several workers, and a diffused double layer was proposed by Gouy[48] and also by Chapman[12]. This view has been extended by Stern[101], so that the electric charge in the liquid consists of two parts, one being immobile and very near the surface, and the other a diffused one. Some of the counter ions appearing in the neighbourhood of the colloidal surface are not osmotically active.

Mention may be made of numerous colloidal solutions obtainable in a non-polar medium like benzene or paraffins. Here ionisation of electrolyte is not possible, yet some workers believe that the electric charge, though very low, is enough to stabilise the suspensions. Little work has been carried out on such sols, and it may be said that the actual mechanism of stabilisation and flocculation is still far from clear. Paints and varnishes, water emulsified in an oil, are some of the examples of importance from the industrial point of view.

SCHULZE—HARDY LAW

The lyophobic sols are characterised by their sensitivity towards electrolytes and the coagulation values for the electrolytes are dependent upon the valency of the oppositely charged ions. This regularity is the Schulze-Hardy Law.[55, 96] It is the neutralisation of the electric charge by the oppositely charged ions of the electrolyte, which causes the removal of the electric repulsion and thus the colloid particles become less stable. The Schulze-Hardy Law is applicable to a majority of cases, but there are a number of abnormalities. Wo. Ostwald[84] pointed out that the coagulation of a sol takes place when the activity coefficient of the precipitating ion reaches a certain value, which is constant for the ions of all valencies, but this is limited in its usefulness.[118] Besides pure electrostatic attraction of the oppositely charged ions their specific character is also important. Thus several monovalent cations, which are highly adsorbed by a negatively charged colloidal unit, possess coagulating powers comparable to that of a bivalent or even a trivalent cation. The positive radical of an univalent alkaloid such as strychnine from its hydrochloride is as potent a coagulating ion as the trivalent aluminium ion for arsenious sulphide sol.

Ghosh and coworkers[3] pointed out that several other factors are equally important in describing the coagulating power of an electrolyte. They suggested that the chemical interaction between coagulating and peptising ions is significant in determining the coagulating power. Similar observations are recorded for hydrous stannic oxide sol peptised by potassium hydroxide.[127] The high coagulating power of such cations as cupric, lead, silver etc. for the various sulphide sols is due to the formation of insoluble sulphides with the stabilising anions viz., sulphide. The hydroxonium ion is a powerful coagulating agent for various resin sols.[74a] Ghosh and coworkers[46] have pointed out that it is due to the depression in the ionisation of complex organic acid obtained by the hydrolysis of the resinous matter, which makes the sol unstable. Ghosh and coworkers[37] have shown that a large number of polyacid sols, which are negatively charged, becomes stable in the presence of traces of hydroxonium ions, whilst the traces of hydroxyl ions sensitise these sols. The work of Jander and coworkers[58] and of Ghosh and collaborators[37] have shown that for such polyacids as silicic, vanadic, tungstic, molybdic etc., the polymerisation of the acid is increased by hydroxonium ions and *vice versa*. Hence, in the presence of traces of an acid heavier anions are formed, which are responsible for the stability of such colloidal systems.

It is now necessary to examine Whetham's rule[121] relating the precipitation values of the monovalent, bivalent and trivalent coagulating ions *viz.*, $P_1 : P_2 : P_3 :: 1 : x : x^2$, x being smaller than unity. In most cases the precipitation values for polyvalent ions are larger than those required by it. Chakravarti, Ghosh and Dhar[11] pointed out that the double layer controls the action of the coagulating ions, so that these precipitation values are in the ratio of $1 : \frac{1}{2}\alpha : \frac{1}{3}\alpha^2$ where $\alpha = e^{\frac{-Q\varepsilon/D_r}{kT}}$ and Q is the electric charge on the colloid particle, ε is the electronic charge, k Boltzmann Constant, D dielectric constant and T is the absolute temperature. In deriving this relation, the specific action of the ions, *viz.*, their adsorbility, chemical interaction with the stabilising ion etc. have not been taken into consideration. It will be seen from this relation that the value of α tends to increase and becomes unity, when the electric charge decreases. The relation tends to become $1 : \frac{1}{2} : \frac{1}{3}$ under limiting conditions. Gore and Dhar[47] have confirmed this conclusion, when they found that the difference in the precipitation values of monovalent, bivalent and trivalent coagulating ions tends to decrease as the sols are continuously dialysed.

De Boer[16] and Hamaker[53] considered the energy of interaction of two colloid particles, arising out of the repulsion due to the electric charge, and the attractive force similar to van der Waal forces. Verwey and Overbeek[110] extended it and suggested that the precipitation values of mono-, di- and tri-valent coagulating ions should be in the ratio of $1 : (\frac{1}{2})^6 : (\frac{1}{3})^6$, which is only approximately true. It also fails to show that for the same coagulating ions the ratios of their precipitation values change considerably with the purity of the sols.

CONCENTRATION OF A SOL AND ITS STABILITY

The effect of the concentration of a sol on the precipitation values of an electrolyte has been investigated by several investigators. Burton and Bishop[10] stated that with the decreasing concentration of a sol, the precipitation values for the trivalent coagulating ion decrease, for the bivalent they remain practically constant, and for the monovalent they increase. This was found to be true in some sols, mainly of arsenious sulphide, investigated by Mukherjee and coworkers,[76] Weiser and Nicholas,[114] Kruyt and Spek[61] and several others. This observation known as Burton and Bishop's Rule is not true for all sols. Ghosh and Dhar[43] have investigated the effect of concentration of dispersed material on the stability of a large number of sols. They found that for sols of the hydrous oxides of iron, aluminium, chromium and tin etc., the precipitation values of all coagulating ions diminish with the decreasing concentration. Wannow and collaborators,[113] report that Burton and Bishop rule is applicable for these hydrous oxide sols specially for sufficiently dilute ones. Sorum[100] observed that the effect of dilution on the stability of hydrous ferric oxide towards electrolytes is affected by its purity.

Several investigators have ascribed the greater stability of the dilute sols, specially towards monovalent coagulating ion, as due to lesser probability of contact between charged colloid particles with the coagulating ions. Ghosh and Dhar[43] showed that Burton and Bishop rule is true for arsenious sulphide sol even if the factor of probability is considerably reduced by increasing the time of observation. These authors concluded that Burton and Bishop rule is the result of the specific properties of the electrolyte added and the dispersed particles. Where similarly charged ions are appreciably adsorbed by the colloid particles, the sol on dilution becomes more stable towards the electrolyte. They showed that the sol of hydrous ferric oxide obtained by Krecke's method can be coagulated by hydrochloric acid, and its precipitation value increases with the dilution of this sol; whilst the precipitation value for potassium chloride decreases with dilution.

It is necessary to note here that the precipitation value of an electrolyte for a sol is dependent on a number of factors, including the time and rate of coagulation and the amount of stabilising electrolyte present. Undoubtedly, by diluting a sol, these criteria change which should be taken into consideration for investigating the stability of a sol affected by its concentration.

IONIC ANTAGONISM

It was noted by Linder and Picton,[69] that arsenious sulphide sol containing small quantities of such electrolytes as KCl or NaCl, requires more of barium chloride, strontium chloride etc., for coagulation. This observation has since been confirmed by several workers.[5, 30] This phenomenon is usually known as ionic antagonism and is specially important in biological action of electrolytes. Neuscholz[80] reported that in the precipitation of negatively charged Lachithine sol the univalent cations nullified the action of divalent cations. Ringer[94] showed that when the heart of a frog is perfused with a solution of sodium chloride isotonic with blood, the beats gradually diminish and ultimately cease. If calcium chloride is now added, the excitability is returned and is soon followed by spontaneous beats. Loeb and coworkers[70] and Osterhout[83] and several others have shown, that some live cells can thrive in a mixture of electrolytes as NaCl, KCl and $CaCl_2$. Freundlich and coworkers[30] for the first time suggested that ionic antagonism is due to the difference in the solvation of the colloid particles effected by the coagulating ions. Weiser[115] ascribed the antagonistic action of the electrolytes to the mutual decrease in the adsorption of the coagulating ions. On the other hand, Ghosh and Dhar[44] pointed out the adsorption of similarly charged ions as the main cause for ionic antagonism. Thus, it can be shown that a positively charged sol of hydrous ferric oxide when coagulated by a mixture of HCl and KCl or of HCl and K_2SO_4 develops antagonism, inspite of the fact that the adsorption of chloride and sulphate ions by hydrous ferric oxide is more in the presence of traces of an acid.

The ionic antagonism is, however, usually observed for electrolytes of widely different coagulating powers and is limited to some specific electrolytes and sols. Thus, positively charged sols of various hydrous oxides when coagulated by anions from mixtures of KCl and K_2SO_4 are found to be additive. The coagulation of negatively charged arsenious sulphide by KCl and $BaCl_2$ develops ionic antagonism. The antagonism cannot be explained by the change effected in the activity of the ions of one electrolyte in the presence of others.

ACCLIMATIZATION

It is interesting that in the coagulation of colloids by electrolytes, the amount required for coagulation is greatly influenced by the rate at which the electrolyte is added. It was noted by Freundlich[26] that for arsenious sulphide sol the amount of KCl or $BaCl_2$ required for coagulation was more, when the electrolytes were added in steps, than the amounts required to coagulate the same by the addition of these electrolytes all at once. The sol under such circumstances, is said to be acclimatized to the presence of the electrolytes. These observations are similar to that of the Danysz effect observed in the toxin antitoxin reaction. When diptheria toxin is treated with its antitoxin, the reduction in toxicity depends on the manner in which it is added. The aniitoxin is not sufficient to neutralise the same amount of toxin when added little by little, leaving intervals between each addition.

Freundlich[27] first suggested that such acclimatization in coagulation process is due to the difference in diffusion, during the rapid or slow addition of an electrolyte to a colloid. Weiser[116] is, however, unable to accept the explanation of Freundlich. According to him acclimatization occurs due to the partial agglomeration, which may carry down some coagulating ion, so that its concentration decreases and a greater amount of the electrolyte is required to precipitate the sol. It should be mentioned here that acclimatization is not observed for all lyophobic sols. This is observed remarkably for arsenious sulphide coagulated by KCl or $BaCl_2$, but is hardly perceptible for hydrous ferric oxide sol coagulated by potassium sulphate or potassium oxalate.

In 1926, a new observation was made by Ghosh and Dhar.[45] They showed that when a sol of arsenious sulphide is coagulated by the stepwise addition of such coagulating electrolytes, as strychnine hydrochloride or crystal violet, considerable partial precipitation occurs. By such gradual addition the sol requires much smaller quantities of these electrolytes for complete coagulation than the amounts required by their addition all at once. In short, these authors found that this sol instead of being acclimatized becomes sensitised to their action, when the addition is extended over for some time. They named this phenomenon as 'negative acclimatization' and this observation completely does away with all other theories. Ghosh and Dhar advanced an explanation for acclimatization (positive and negative), based on the adsorption of either the similarly charged ion, or the oppositely charged one by the colloidal particle. According to them, if the ion carrying the same charge as the colloidal particle is appreciably adsorbed from a very dilute solution of an electrolyte, positive acclimatization will result, whilst for the high adsorption for the oppositely charged ions negative acclimatization is developed.

Ghosh and Dhar[46] for the first time corelated Burton and Bishop rule, ionic antagonism and acclimatization for the coagulation of a lyophobic sol, as the direct influence of the adsorption of similarly charged ions. Hence, any theory relating to the action of an electrolyte in the coagulation process has to take into account the specific part played by similarly charged ions, the influence of which cannot be neglected when it is highly adsorbed on the colloidal surface.

INFLUENCE OF NON-ELECTROLYTES

A large amount of literature is available on the influence of non-electrolytes on the stability of some lyophobic sols. Freundlich and Rona[29] found that hydrous ferric oxide sol becomes more sensitive towards electrolytes on the addition of such capillary active substances as camphor, thymol, urethane etc. Kruyt and Duyn[64] noted that iso-amyl alcohol sensitized arsenious sulphide sol towards mono and trivalent coagulating ions, but stabilised it towards a divalent one. Rona and George[95] found that camphor and thymol added to a kaolin suspension make it so unstable as to precipitate it. Phenol increases the precipitation value of $BaCl_2$ for arsenious sulphide sol. Chaudhuri and Mukherjee[77] reported that methyl alcohol sensitises the sol for $BaCl_2$, but ethyl alcohol stabilises it towards the same electrolyte. Both methyl and ethyl alcohols have been found to sensitise arsenious sulphide sol towards KCl, HCl and $AlCl_3$. Chatterji and Tiwari[13] studied the rate of coagulation of negatively charged arsenious sulphide by $BaCl_2$ and positively charged hydrous ferric oxide by K_2SO_4, in the presence of different alcohols. They have concluded that both the sols are sensitised by lower concentrations of ethyl and methyl alcohols, but at higher concentrations they show some protection. Hence, there is an optimum concentration of these alcohols for sensitisation and there is an isoactive point.[123] Other alcohols are found to protect both the sols at all stages. Chatterji and Tewari used spectrophotometric method for determining the extent of agglomeration and for such an optical method, the variation in the refractive index of the medium may affect the conclusions drawn from the observed results.

It may, however, be said that no general conclusion can be drawn as to the effect of non-electrolytes on the stability of sols. Wo. Ostwald[85] ascribed the effect of non-electrolytes to the change in the dielectric constant of the medium. Freundlich[28] adopted this view and showed that lowering of the dielectric constant leads to the dimunition of the charge on the particle and hence its stability. In confirmation of this view, Keesom[59] observed that urea and glycol stabilise arsenious sulphide sol towards electrolytes, as these non-electrolytes increase the dielectric constant of water. Sugar, which stabilises a number of sols, has been reported to increase the dielectric constant of water, but Mukherjee[75] found decreasing cataphoretic speeds of colloid particles of arsenious sulphide in its presence, indicating a decrease in the electric charge.

The effect of the addition of a non-electrolyte to a hydrosol on its stability towards different electrolytes is not always the same, and the simple explanation of Freundlich and others for the action of a non-electrolyte cannot be accepted as a general one. Some authors as Weiser[117] suggested the diminution of adsorption of both the precipitating and stabilising ions by the addition of a non-electrolyte. This diminution by non-electrolytes for stabilising ions will decrease the stability, whilst that for the coagulating ion would require a larger quantity of the electrolyte for coagulation. This conclusion of Weiser appears to be attractive, but it requires more experimental verification. It should be mentioned that Mukherjee[75] could not contribute to this explanation. Chaudhuri[14] introduced another factor, viz., variation in the interfacial tension of the colloidal surface effecting the coalescence of the colloid particles. Similarly, the variation in the solvation of the particle may also be considered as another important factor. The influence of non-electrolytes on the ionisation of the electrolytes present cannot be overlooked. Thus several factors are involved in determining the stability of a sol in presence of a non-electrolyte, as is usually noted by determining the precipitation value of an electrolyte. It is for this reason that various observations recorded in literature cannot be properly understood. For a large concentration of an added non-electrolyte, the change in the dielectric constant may have a striking influence, but for smaller additions of a non-electrolyte the situation is quite complicated.

INFLUENCE OF AGEING ON STABILITY

A lyophobic sol has a tendency to aggregate on keeping. Enough literature is available on the ageing of sols, though purely the effect of time on the stability of colloidal systems is difficult to investigate, for it is not possible to exclude all external factors. The surface of the container and all sorts of radiations, including ultrasonic and cosmic, are known to have appreciable effect on some sols. Despite these limitations, experimental results show that ageing of different colloid particles gradually leads to their growth making their surface inert. The effect is very similar to that observed in the ageing of the individuals. The tissues are complicated disperse system in a living being. The particles in young organism are generally smaller than the older ones.

Exhaustive work on the ageing of a large number of hydrous oxides has been carried out in our laboratories. We have noted that precipitates of some hydrous oxides on ageing become so inert that they lose all chemical reactivity. This observation is more magnified in the case of hydrous oxides of amphoteric nature, i.e., those of zinc,[1, 108] aluminium,[49, 102, 103] chromium,[103, 104, 106] tin[19, 65] silicon and even copper, [20, 74] nickel[97, 98] and iron.[21, 22, 50, 51, 52] If left to themselves suspended in water, they become highly insensitive to the action of either acid or alkali, as the case may be. It has been further shown that the characteristic effect of ageing on the respective hydrous oxide is also determined by the temperature, and the pH of the solution from which the precipitate separates. All these observations have been explained from the viewpoint of the polymerising tendency of these hydrous oxides, specially those of amphoteric nature. Hence, the effect of ageing on the stability of such hydrous oxides is considerably influenced by the decrease in the surface activity of the particles, which determines the adsorption of both stabilising and coagulating ions.

Several years ago, Ghosh and Dhar[45] reported that a sol of arsenious sulphide becomes more unstable towards its coagulation by potassium chloride, barium chloride etc., but requires more of strychnine hydrochloride for its coagulation on ageing. A sol of hydrous ferric oxide shows slight decrease in the precipitation values for potassium chloride and potassium sulphate, but for hydrochloric acid it is very prominent. The high precipitation value of an alkaloid cation for arsenious sulphide sol, is due to its high adsorbability which decreases with its increasing age, so that more of it is required for coagulation. Hydroxonium ions stabilise hydrous ferric oxide sol, so that on ageing it becomes very unstable when coagulated by hydrochloric acid.

On ageing a sol undergoes a number of changes. Malfitano[73] considered that hydrous oxide of iron contains ferric oxychloride, but this gradually undergoes hydrolysis to form hydrous ferric oxide and hydrochloric acid. The increase in the conductance of hydrous ferric oxide sol on ageing, has been observed by several workers. Ghosh and coworkers[40] ascribed this to the liberation of hydrogen ions present in the adsorbed state on the particles, which have a tendency to grow. It is also known in the case of a sulphide sol, e.g., arsenious sulphide, that with progress of time the sol hydrolyses to form arsenious acid and hydrogen sulphide, which if in contact with atmospheric oxygen forms thionic acids and also collodial sulphur. A class of colloids, as those of vanadic, silicic, tungstic and molybdic acids, gradually polymerises and becomes unstable.

It has been found that colloidal silver chloride becomes coarser more rapidly than silver bromide, and silver iodide is the most stable of the halide sols on ageing. The ageing effect has been found to increase with increasing temperature, when there is a decrease in the number of particles, caused by an actual transport of matter from the smaller or more soluble particle to a larger one.

EFFECT OF RADIATIONS

Radiations of all types as, X-ray, α-and β-rays, ultraviolet, sonic and ultrasonic, have been found to affect the stabilility of sols. In some cases they stabilise, whilst in many cases they make the sols unstable. Of the various radiations the effect of β-rays on the colloids has been extensively studied.[81] It is found that in most cases, whether the colloids are positively or negatively charged, they become unstable. Similar observations have been recorded by several workers on the effect of visible and ultraviolet light on different sols. During the action of such different radiations, other physical properties of the sols such as viscosity, conductivity and optical behaviour are also affected.

In recent years, considerable interest has arisen on the influence of ultrasonic radiations on colloidial systems. The dispersion of precipitates and the formation of sols and emulsions by ultrasonic radiations was first observed by Wood and Loomis[124] and it is possible to disperse a large number of substances like oil, mercury, sulphur, graphite, sulphides, oxides of metals etc. by these radiations. In our laboratories colloidal solution of manganese dioxide could be obtained by the decomposition of potassium permanganate in aqueous solution and hydrous ferric oxide sol by the hydrolysis of ferric chloride on exposure to ultrasonics. The effect of radiations on gels and also on high polymer solutions is important. The depolymerising action of ultrasonic waves in the case of macromolecules has been found to be restricted to intermediate concentrations. According to Schmid[96a] it is necessary that the macromolecules should form a constant structure, since the isolated molecule is too small when compared to the wave length of the radiation. At high concentrations the structure becomes so stable that it is able to withstand the effect of ultrasonics.

The influence of ultrasonic waves on the viscosity of solutions of gelatine in water and of rubber in toluene is interesting. If such solutions are exposed to ultrasonics of moderate intensity, the viscosity immediately diminishes, but after a certain lapse of time it attains its initial value. An observation has been made in our laboratories[7] that a sol of ferric succinate capable of yielding gel on coagulation, when exposed to this radiation, does not show any remarkable change in viscosity. When the sol is left to itself after the exposure, it develops a high viscosity and greater pseudoplastic properties. It may be said that the ageing effect on this sol leading to its unstability is magnified after exposure to ultrasonic radiations.

ZETA-POTENTIAL

The stability of a lyophobic sol is often related to zeta-potential measured by cataphoresis. Ellis and Powis[24] concluded that when the zeta-potential reaches a critical value by the addition of an electrolyte to an emulsion, it becomes unstable. This suggests that when the electrical repulsion arising out of the charge on the colloid particle decreases to a minimum value, it is overcome by the forces causing aggregation, so that coagulation sets in. Later work of Kruyt and coworkers[62] and the contributions from the Calcutta School[76] tend to show that existence of a definite critical zeta-potential necessary for coagulation is not correct. The measurement of this zeta-potential by different electrolytes at their equicoagulating concentrations do not give the same values. Very recently,

B. N. Ghosh and coworkers[34] have shown that the observed zeta-potential is related to specific conductance of the sol containing the added electrolyte. They found the evaluated zeta-potential in the presence of equicoagulating concentrations of different electrolytes to be the same measured either by electrosmosis or electrophoresis. These observations, therefore, show that the zeta-potential decreases to a critical value at the equicoagulating concentrations of electrolytes.

A force of attraction similar to that of London—van der Waal has been considered by some authors[17, 67, 118] as operative in aggregation. The total interaction of the two forces, repulsive and attractive, between the colloid particles at different distances is calculated and attraction is found to predominate at very small and very large distances. At an intermediate distance the repulsion may predominate, so that the resultant force is such that the separation between the particles will occur.

It is well known that zeta-potential refers to the potential difference at the immobile layer and the medium. It is also clear that aggregation process starts at the contact of the surfaces of two colloid particles. Hence, the electric charge on the colloid surface is more important than the potential difference which determines the electrokinetic behaviour. Zeta-potential, therefore, may not provide a true picture of the stability of a sol. In all cases, however, there is a decrease of zeta-potential, when coagulation is effected by an electrolyte. This happens by the compression of outer layer surrounding the dispersed particle finally leading to the discharge of colloid surface itself by counter ions. In general, the thickness of double layer is likely to be reduced to a greater degree with the increasing valency of the oppositely charged ions from the electrolyte added.

All this picture of the mechanism of coagulation process is qualitative. It does not clearly state as to how the oppositely charged ions neutralize the electric charge on the colloid particles. By the addition of an electrolyte to a sol, the density of the charge of the Stern layer may increase and the counter ions are taken up on colloid surface to neutralize the charge. We have recently observed[98b] that all chloride ions present in a hydrous ferric oxide sol peptised by hydrochloric acid are not osmotically active, and cannot be completely replaced by adding potassium sulphate to the sol. We have, therefore, concluded that some of the oppositely charged ions are associated with the colloid particles. Moreover, it has been observed by Whitney and Ober[122] that equivalent amount of various cations are found associated with arsenious sulphide sol, when coagulated by electrolytes. Weiser and Milligan[119] observed the simultaneous adsorption of sulphate and the displacement of chloride ions from the Stern layer, and that the amount of sulphate found associated with the precipitate was larger in quantity than the chloride displaced from the double layer.

Verwey and Overbeek[109] pointed out that the role of the zeta-potential is less prominent although the electrical double layer is of fundamental importance for the stability of sols. Hamaker[53] considered different types of potential curves by superimposing attractive potential due to London—van der Waal forces, with the repulsive potential due to the double layer surrounding a colloid particle. This view of Hamaker was challenged by Langmuir,[66] but was supported by Levine and Dube[68] and Corkill and Rosenhead.[15] The attractive force is undoubtedly similar to cohesive force. When coagulation sets in, the particles grow and after a certain size is reached, the Brownian movement decreases enormously leading to precipitation. With the progress of aggregation, the attractive force is bound to decrease in magnitude, for the free surface continuously decreases with aggregation, so that there is a decrease in the cohesive force.

KINETICS OF COAGULATION BY ELECTROLYTES

Ultramicroscopic observations on lyophobic sols show that the addition of an electrolyte much below the precipitation value causes no apparent change. As the concentration of the electrolyte is increased, there is a range of slow coagulation followed by a rapid one, so that the coagulation time for any further increase in the electrolyte concentration remains practically constant. Smoluchowski[112] first considered the rate of aggregation of these colloidal particles for the rapid coagulation and obtained the relation $\Sigma n = n_0 / 1 + 4\pi DRn_0 t$ where Σn particles are left out of the total number of particles n_0 at any time t. D denotes the diffusion constant and R the effective distance of attraction. The value of $\frac{1}{4}\pi DRn_0$ is often denoted by T, where T is the time for aggregation at a stage, where the total number of particles left is exactly half the original number. This equation of Smoluchowski in the region of rapid coagulation has been verified by Zsigmondy[128] and other workers. For slow coagulation, Smoluchowski modified his equation so that $T = \frac{1}{4}\pi DRn_0 \varepsilon$, where ε is less than unity, so that all collisions are not effective for agglomeration, because of the residual electrical charge on the particles. Obviously, this equation is very similar to that for rapid coagulation, except for the fact that T increases in slow coagulation. The aggregation process for selenium sol by the addition of an electrolyte was investigated for slow coagulation by Kruyt and van Arkel[63] using ultramicroscope. They found that the value of T, does not remain constant at different stages of aggregation. The value in most cases increases with aggregation, so that the coarser particles become more stable. In general, it has been noted in the region of slow coagulation of sols like those of selenium and gold that the values of ε regularly decrease with time.

Paine[86] studied the rate of coagulation of a copper sol, contaminated with cupric hydroxide, by potassium chloride, by estimating the amount of copper left in a suspended state at different intervals of time. Oden[82] used a sedimentation balance to measure the rate of coagulation by ammonium nitrate for barium sulphate suspension peptised by citric acid. Freundlich and Ishizaka[25] followed the rate of coagulation of hydrous aluminium oxide by potassium chloride, by noting the changes in the viscosity of the sol. In all these cases the rate of aggregation shows an autocatalytic character. Ghosh and Chakravarti[38] followed the slow coagulation of a hydrous ferric oxide sol prepared by Krecke's method and also of a sol of ferric phosphate, by potassium chloride. The sols containing a definite amount of potassium chloride were taken from time to time, centrifuged for a minute to remove the coagulated material, and then the suspension estimated for the remaining iron. The results show that the ferric phosphate sol, which is viscous and yield gels, gives an autocatalytic nature for the rate of coagulation. The hydrous ferric oxide sol does not show this behaviour, the amount of suspended material regularly decreasing with time. A complete review of the literature will show that for several sols the speed of slow coagulation has a tendency to develop an induction period, whilst in many other cases there is a continuous and steady decrease in the rate. Thus it is clear that Smoluchowski's equation fails in the case of slow coagulation, so much so that in some cases the very nature of the process seems to differ. Most of the methods adopted for the measurement of the rate of coagulation are, however, based on the observation of the changes of different physical properties of a sol, which vary with the progress of aggregation. Thus, changes in optical property, interfacial tension and viscosity have been measured for the study of rate of aggregation of a sol effected by an electrolyte. It is not therefore surprising that some authors do not consider these results of significance, because such properties may not be a direct function of the size of the colloid particles.

Mukherjee and coworkers[79] used the optical method in studying the rate of coagulation of sols of gold and arsenious sulphide. They have shown that in the region of slow coagulation by different amounts of the electrolytes, Smoluchowski's equation is not valid. As a sol of a given concentration showing the same absorption, contains the colloid particles at the same state of aggregation, the ratio of the two periods of time for the production of the same optical condition, for two different concentrations of an electrolyte will remain constant throughout the course of aggregation. Very recently, Rai and Ghosh[90] used the spectrophotometric method for following the rate of coagulation of a yellowish sol of colloidal silver turning blue on coagulation, by different electrolytes. They find that the value of ε does not remain constant throughout the process of aggregation.

Let us now consider the Smoluchowski's equation specially in the region of slow coagulation. The value of the diffusion constant D decreases with the increasing aggregation of colloid particles. It is, therefore, not unusual that the value of the whole factor $\frac{1}{4}\pi D R n_0 \varepsilon$ or T increases with the progress of aggregation, so that larger particles become more stable. It should be pointed out here that in the experiments for coagulation, stirring or mechanical agitation considerably affect the time of coagulation. We have repeatedly observed that the effect of mechanical agitation becomes specially prominent, when the aggregation has proceeded far. This happens because the larger particles have very slow diffusion, so that they are brought in contact only by mechanical agitation.

The value of $D\,R$ may be constant throughout the process of aggregation, because $D \propto \frac{1}{R}$ if R equals to the actual radius of the particle. We should, however, remember that aggregation is the result of the decrease in free energy of the surface and necessarily, the range of attraction R need not be proportional to the actual size of the particle. It tends to decrease quickly for larger particles leading to a more stable state of the system. Our knowledge of free surface energy of colloid particles is, however, not yet fully clear. Some workers have ascribed the greater stability of the coarser particles to the increased density of electric charge on the aggregated colloid particle, thus providing a higher potential barrier in the process of coagulation.[80]

It is now necessary to consider the observations, where the rate of aggregation is autocatalytic. The observations can only lead to the conclusion that the value of ε , or the fraction of the total number of collisions that is successful, is very small in the earlier stages. This can be explained on the view of Ghosh[35] that the charge neutralization of a particle by counter ions takes place slowly, specially in the region of slow coagulation. Further, if the aggregation process is also slow, which is very likely for a sol having some lyophilic character, the whole process of aggregation assumes the character of a consecutive reaction having an induction period. Ghosh has pointed out that in the region of slow coagulation, the autocatalytic process is shown mostly by a sol with some lyophilic character. In the case of a truely lyophobic sol, the rate of charge neutralisation mainly determines the aggregation process. For such sols, as soon as the charge is neutralized upto a certain limit, the aggregation force being prominent they coalesce immediately on contact.

In short, therefore, any theory contemplating to provide a picture of coagulation by an electrolyte, specially in the slow coagulation region, must take into account the changing values of ε, D and R during the progress of aggregation. R will be characterised by the specific nature of the dispersed substance, and ε by the concentration, valency and the specific nature of the counter ion.

ELECTROLYTE CONCENTRATION AND STABILITY

On the increasing addition of an electrolyte to a sol the coagulation state is reached more quickly but there is insufficient literature on this subject. It may be said that the value of ε is small for the lower concentrations of an electrolyte leading to a longer period for coagulation. The relation between the magnitude of ε and that of the double layer potential with the concentration of the electrolyte is not very well known. The theory of Fuchs[31] for aerosols has been applied by Verwey and Overbeek[110] and Reerink and Overbeek[92] who consider that the stability factor W is equal to unity, when the two colloid particles have no repulsive energy, so that every collision leads to aggregation. With increasing repulsion between the colloidal particles, the fraction ε of the collisions leads to coagulation. In other words, W or the stability factor is similar to ε of the Smoluchowski's equation for the process of slow coagulation. Reerink and Overbeek[92] have shown that there exists a linear relationship between log W and log C, C being the concentration of the electrolyte, so that, $\log W = -K_1 \log C + K_2$. These authors verified this relation for some sols slowly coagulated by electrolyte, by finding out the value of W at zero time of the addition of an electrolyte to a sol, which characterises its stability.

Paine (86) gave an empirical relation between the time of coagulation with the concentration of coagulating electrolyte. The relation is $\log t = k - p \log C$, where k and p are constants. Since W is proportional to coagulation time, this relation is similar to that given by Reerink and Overbeek. It has been found to be approximately true, specially for the process of gelation of some sols, as those of ferric succinate, ferric phosphate etc. effected by the addition of an electrolyte. It must, however, be clearly stated, that this equation of Paine may be only true if the values of W or $1/\varepsilon$ do not remarkably change during aggregation. In the process of gelation, we have repeatedly emphasised that the colloidal units remain attached in a loose state, when the gel is just formed, and high aggregation is considerably checked by the solvation of colloidal particles. The relation of Paine is thus found applicable to such gelation processes.

The empirical equation of Bhattacharya and coworkers[4], relating the concentration of an electrolyte with time of coagulation, also needs consideration. The equation is:

$$1/c - a = \frac{n}{m} t + \frac{1}{m}$$

where, m and n are constants and a is the concentration of the electrolyte below which no aggregation occurs. This equation has been shown to be applicable in many cases. It is not possible to have any physical concept for the value of a, because all lyophobic sols are thermodynamically unstable though the particles may remain in a suspended state for several years. We have, therefore, to conclude that a represents the minimum concentration of an electrolyte below which the stability factor (which is finite) is not affected. This shall be referred to later.

EFFECT OF TEMPERATURE ON STABILITY

It has already been said that in most cases, the lyophobic sols become unstable on ageing and warming usually accelerates the ageing effect. Ghosh and coworkers[97, 105] have repeatedly shown that hydrous oxide suspensions when warmed, lose their chemical reactivity and adsorptive capacity considerably, and lyophobic sols generally become more unstable towards electrolytes. Very little reference, however, is available in literature on the coagulation of lyophobic sols at different temperatures.

Hurd and Latteron[56] investigated the effect of temperature on the time of set of silicic acid gels. Similarly, Yadava and Ghosh[125] studied the gelation of ferric, chromium, calcium, barium and strontium silicates and very recently Bose and Mushran[9] the sols of ferric succinate. Yadava, Bose and Ghosh[126] showed that the separation gels as those of ferric silicate, borate, phosphate etc., are very similar to the phenomenon of coagulation. They obtained a relation between the concentration of a sol with the time of set, in presence of a definite amount of an electrolyte added to the sol for gelation. It has been shown in numerous publications from our laboratories that processes of coagulation and gelation are similar.

Hurd has calculated the heat of activation for the gelation of silicic acid, analogous to the Arrhenius' heat of activation for a homogenous chemical reaction. If *t* is the time of set, the rate of gelation becomes proportional to $1/t$, and

$$-\log t=\log Z-\frac{E}{2{\cdot}303\,RT}$$

The plot of log *t* against $1/T$ gives a straight line, the slope of which determines *E*, the heat of activation for the gelation process. It is found to be about 20 K.cals. for one gram mole of silica forming a gel by the interaction of sodium silicate and hydrochloric acid. Similar values have been obtained by other workers in the metathetic process of the formation of different gels. Bose and Mushran[9] calculated the heat of activation for ferric and aluminium succinate gels, obtained by the interaction of sodium succinate with different amounts of the metal chlorides. They find that the heat of activation for gelation decreases with the increasing amount of metal chloride left free in the system, though the rate of gelation decreases. They have obtained similar results for the gelation of ferric succinate sols peptised by different amounts of ferric chloride. Generally, the reaction at ordinary temperature with high heat of activation is slow and *vice versa.*

The rate of chemical reaction is given by ;

$$\frac{dx}{dt}=Z\,e^{-E/RT}$$

where, *Z* is the collision number and *E, R* and *T* have the usual significance. In many cases, the observed reaction rates are less than those calculated by this equation. This is explained from viewpoint that all collisions of the molecules bearing requisite amount of energy of activation are not successful, so that $\frac{dx}{dt}=pZe^{-E/RT}$, and *p* in some cases has been found to be as small as of the order of 10^{-9}.

According to the concept of the theory of absolute reaction rates, we have,

$$\frac{dx}{dt}=\frac{kT}{h}\cdot e^{\Delta S/R}\cdot e^{-E/RT}$$

where ΔS and E represent the change in entropy and heat content respectively, between the activated complex and the reactions. In other words, the value of ΔS in the formation of a transitory complex also guides the rate. It is found that for a reaction between similarly charged ions in solutions, the value of p and hence ΔS decreases. Hence the activated complex has a lower entropy than that of the reacting ions.

The above considerations reveal that the value of p is likely to be very small when electrically charged colloid particles unite to form an intermediate complex, of which a large amount may disintegrate to the original condition. Hence, a very small fraction of the collisions leads to aggregation.

During the gelation of ferric succinate by the interaction of ferric chloride and sodium succinate, a positively charged colloidal succinate is first formed by the absorption of ferric or hydroxonium ions. The charge on the colloid particles is large for the excess of ferric chloride present. The charge on the colloid surface is due to the statistical distribution of absorbed ions. It is only at the spots which are least covered by the ions imparting the charge to the surface, that the repulsion will be least and gelation will occur. This concept[9] explains the low value of p, i.e., only a very small fraction of the collisions leads to gelation.

We have now to obtain a physical picture for the lower values of E, in the presence of large excess of ferric chloride. The aggregation of the colloid particles arises out of the surface force which tends to decrease. If the colloid particles are small, the surface area is large and necessarily they have greater tendency to aggregate. On the other hand, larger colloidal units have smaller surface area leading to lesser tendency to aggregation. Hence the value of E or heat of activation is smaller for the gelation of sols containing excess of the peptising electrolyte.

MECHANISM OF COAGULATION

A lyophobic sol is in the true sense unstable, and Verwey considers that the stability factor of a lyophobic sol is of the order of 10^{19}, so that ordinarily the sol may be supposed to be stable. For the sol of hydrous ferric oxide, we have repeatedly observed that on ageing it shows greater electrical conductance, and requires a lesser amount of an electrolyte to coagulate than required by the fresh sol. That is due to the gradual liberation of hydroxonium ions in absorbed state on ageing, leading to a decrease of the charge on the colloid surface. The unstability of a lyophobic sol is accentuated by the addition of an electrolyte, but it shows a different behaviour from the ageing effect. Rai and Gosh[91] have recorded that by the addition of an electrolyte like KNO_3 or K_2SO_4, the sol not only liberates the fixed chloride ions of the double layer, but also there is an increase in the OH' ion concentration in the sol, so that the electrical conductivity contributed by it decreases. Increase in the alkalinity for different hydrous oxide sols as those of aluminium, thorium, beryllium and zirconium has also been reported by different workers. Thomas and coworkers[107] suggested that the colloid particles of these hydrous oxides consist of oleate or possibly oxolated hydroxy-compounds of Werner type. Thus the increased pH value can be attributed to the replacement of OH′ groups by the anions of the added salt. X-ray analysis performed by Böhm and Niclassen[8] and later by Weiser and Milligan[120] ruled out the formation of any such compound. Moreover, it becomes difficult to conceive how the electric charge on the colloid particle is diminished, when an ion enters the micelle and releases OH′ ions by replacement. Rai and Ghosh[90] have shown that whilst there is liberation of alkali from some positively charged sols, there is liberation of an acid in the case of some negatively charged sols, like hydrous stannic oxide and colloidal silver.

The mechanism of charge neutralization of a colloid particle by the addition of an electrolyte has been discussed by several authors including Freundlich, who considered that equivalent adsorption of ions of varying valencies occurs, when sols are coagulated by different electrolytes. However, we now believe that on the addition of an electrolyte to a sol the oppositely charged ions increase in concentration in the Stern layer and when it becomes high, it neutralizes the charge on the colloid particle. Thus the charge is decreased to a minimum value where the repulsive force is more than counterbalanced by the force operative in the aggregation process. The charge neutralization is thus followed by a release of the counter ions in the double layer, as shown by Weiser and verified by Rai and Ghosh.[90] This mechanism, however, is unable to explain the liberation of alkali in the coagulation of positively charged hydrous ferric oxide sol by an electrolyte. It has been observed that p_h of the sol increased from 4·25 to 7·25 on coagulation with potassium sulphate. It appears, therefore, that the colloid surface carrying positive charge by the specific adsorption of hydroxonium or ferric ions is not completely covered by these absorbed cations. The progressive adsorption of these ions makes the surface positively charged, and the probability of approach of the cations to the surface is considerably diminished. When, the surface is partially discharged by the counter ions, further adsorption of stabilizing ions, already present in the sol, may occur. In this way, the surface is continuously discharged by the oppositely charged ions and again it gets charged by hydroxonium ions from the sol. Such changes proceed till the surface is completely saturated with hydroxonium ions, and the anions finally discharge the surface leading to the process of coagulation. This picture of the action of the counter ions in the earlier stages, suggests a minimum concentration of electrolyte, below which the electric charge on the colloid surface is not affected. Therefore, the sol is left in its original state of stability, as emphasized by Bhattacharya and coworkers.[4]

The coagulation of lyophobic sols by an electrolyte is a complex process. In addition to the electrostatic conditions of the interaction of the colloid particles, either with the counter ions or with the stabilizing ions, the specific adsorptive capacity of the colloid units for both the ions are of sufficient importance. Further, when the aggregation starts the variations in the area of the surface affecting the attractive force for growth, and also the changes in the diffusion constant of the dispersed particles, require consideration. Moreover, the autocatalytic nature of the rate of aggregation observed for some sols suggests, that the aggregation process of the colloid particles by an electrolyte is very similar to the consecutive reactions in chemical kinetics. Several years ago, Ghosh[35] pointed out that the rate of charge neutralization of a colloid particle by an electrolyte is not instantaneous, specially in the region of slow coagulation. The coagulation rate has many similarities with that of the rate of chemical reactions, and we expect more fruitful conclusions by the application of the general theory of the rate process.

CONCLUSION

I have placed before you some important aspects of colloid chemistry concerning the stability of lyophobic sols, in which I have been interested for the last thirty-five years. The stability of lyophobic sols is generally determined by the study of its coagulation by electrolytes. The usual methods for noting the coagulation, however, lack in precision because the mode of the addition of electrolyte, time allowed for coagulation, the concentrations and the specific properties of the sol and the electrolyte, exposure to different radiations and even mechanical agitation affect the observations. Inspite of these difficulties, attempts have been made to elucidate the mechanism of coagulation and the stability of a sol.

The stability of the dispersed particles depends to a large extent upon the nature of the surface forces leading to aggregation. The inherent tendency of the particles to coalesce decreases with progressive aggregation. Investigations of both Physicists and Chemists on such surface forces will throw a flood of light on the mechanism of coagulation. Once the nature of these forces are elucidated, it will be possible to understand the remarkable surface property of a living protoplasm possessing an enormous attempt of self preservation. A protoplasm has a colloidal nature and is the material basis of life.

Evolution and therefore, life is an organised state of matter while death is a state of disorganisation. The main property characterising a living protoplasm is the property of its surface, which may be said to be in a highly organised state of both micro and macro molecules composing it. With the advancement of our knowledge of surface forces operative in the aggregation of colloidal matter and also the advancement of modern Biology, the synthesis of living matter does not appear beyond the realms of possibility. We, however, do not know what man will do when he will be able to synthesise life. Our experience of the past, about some of the great scientific discoveries is not very encouraging. For example, today our very civilisation appears to be on the verge of annihilation due to the discovery of atomic weapons. We are now faced with a vexed problem about our progress and therefore, let every scientific worker have some guiding ethical ideals to govern his actions, so that he can unfold the secrets of nature to make our lives more happy and more glorious.

The scope of research work in colloid science is large. This not only provides academic interests but also solves many problems connected with industry, food and life. In this country we started the study of colloid science early in the history of the development of modern research and I hope that in the years to come, more organised and sustained research work will be undertaken, which shall make a landmark in the progress of colloid chemistry, so far always useful to humanity.

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SECTION OF GEOLOGY AND GEOGRAPHY

President: DR. A. G. JHINGRAN, M.Sc., Ph.D., F.N.I.

PRESIDENTIAL ADDRESS

THE PROBLEM OF BUNDELKHAND GRANITES & GNEISSES

Ladies & Gentlemen,

At the outset I wish to thank you all most sincerely for the great honour you have done me in electing me President of the Geology and Geography Section of this session of the Indian Science Congress Association. I hope that with the kind co-operation of all the members who have gathered here to participate in the deliberations of this session it will be possible for me to discharge the heavy responsibility given to me. I will endeavour my best to justify the trust reposed in me.

I initiate the proceedings of this session with a discourse on the Bundelkhand granites and gneisses which offer multifarious problems of a complex nature. Although occupying a large and prominent place in the northernmost portion of the Indian Peninsula this massif has hitherto more or less failed to attract the attention of the Indian petrologists. This may have been partly due to the fact that unlike many other crystalline rocks of pre-Cambrian age these granites have not been found mineralised to any great extent. I got interested in the problem of Granites about twenty years ago when I had the opportunity to work on some of the pyroxene bearing granites of England. Ever since I felt keenly interested to pursue the subjcet on the Indian Granites, particularly with a view to see the relationship between the different massifs that occupy very large portions of our Peninsula. Much as I wished to work on this problem, circumstances did not offer me an opportunity to take it up for many years. At my suggestion, R. C. Misra undertook the problem and worked on a part of the Bundelkhand rocks. The results of his early deliberations formed the subject matter of a thesis which was accepted for the degree of Doctor of Philosophy of the Lucknow University. I am glad that Misra retained a sustained interest in the subject and along with a band of enthusiastic students he has persistently been working on the problem for the last several years, and has been able to get a number of papers published which throw light on its composition and genesis etc. In recent years I have also had an opportunity to carry out systematic work in the Bundelkhand area along with my colleagues S. M. Mathur, S. N. Puri, R. S. Sharma and P. C. Mathur in the Geological Survey of India. Although we have so far covered only a part of the massif, the results have been interesting and I wish to place them before you.

PREVIOUS WORK

A geological account of Bundelkhand was first written by H. B. Medlicott in 1859. Between the years 1860 and 1869 fairly extensive surveys were made in the various portions of Madhya Pradesh. In 1870 C. A. Hacket published a detailed account of the Geology of Gwalior and Vicinity. The term Bundelkhand gneisses was first introduced by Mallet in 1872. Later W. L. Wilson prepared a detailed geological map of the whole of Bundelkhand on the scale one inch to a mile, but he left no report of his work. Subsequently no work was done in the area for a very long time. During the last 17 years several officers of the Geological Survey of India have worked at different times and places in this region, their results being incorporated in their respective published and unpublished reports. This includes the work done by P. K. Chatterjee (1941-42), D. R. S. Mehta (1944-45) S. Krishnaswamy (1945-46), M. K. Roy Chowdhury (1947-48) and J. P. Srivastava (1951-52). As the work of these officers was mainly connected with mineral investigations, they did not devote much attention to the petrology of these crystalline rocks. Then comes the work of Dr. R. C. Misra and his co-workers, to which I have already made a brief reference, and to relevant portions of which I will have occasion to give further reference later on in appropriate sections. Some work on these granites has also been done by Dr. G. W. Chiplunkar and his students at Sagar University and by V. N. Chhibber at Banaras Hindu University. A bibliography is given at the end.

INTRODUCTION

At the very outset it may be mentioned that the term 'Bundelkhand Gneiss' as applied to the typical rock of this region is a misnomer, the bulk of it being a massive granite. No doubt banded or crudely foliated rocks are also present in certain areas ; these are, however, considerably subordinate. It is therefore more appropriate to describe these rocks as Bundelkhand granites and gneisses.

In these rocks one is struck imminently with the great heterogeneity displayed by them in their texture and mineral composition from place to place. In textures, the variation is from extremely fine grained to quite coarse rocks, occasionally there being porphyritic types also. In mineral composition also the range is fairly wide, there being types with a purely felsic composition and others abundantly rich in ferromagnesian constituents. A further variation is provided by the difference in the colour of the dominant felspars which may be either grey or pink. The granites can thus be classified on the basis of (I) their texture, (II) the nature of the dominant felspar and (III) the presence or absence of ferromagnesian minerals. The scheme adopted in the present work is given below:—

I. *Coarse grained granites*
- (1) with dominant pink felspar and bearing ferromagnesian minerals,
- (2) with dominant pink felspar and with little or no ferromagnesian minerals,
- (3) with dominant grey felspar and bearing ferromagnesian minerals,
- (4) with dominant grey felspar and with little or no ferromagnesian minerals.

II. *Medium grained granites*
(5) with dominant pink felspar and bearing ferromagnesian minerals,
(6) with dominant pink felspar and with little or no ferromagnesian minerals,
(7) with dominant grey felspar and ferromagnesian minerals,
(8) with dominant grey felspar and with little or no ferromagnesian minerals.

III. *Fine grained granites*
(9) with dominant pink felspar,
(10) with dominant grey felspar.

This classification being mainly dependent on the general appearance as presented by the grain size and the varying constituents, it is natural that a personal factor would have a considerable amount of play in deciphering whether a rock is to be put in one category or the other. However as systematic mapping progressed it was noted that no serious difficulty was encountered by the parties working separately with regard to determining the category of the texture and the nature of the dominant felspar. With respect to the ferromagnesian minerals, however, it was found difficult at times to gauge whether this amount was high enough to justify the inclusion of the rock in the 'with ferromag. group' or that it was low enough to permit its being graded in the type 'with little or no ferromags.' In such cases it was frequently experienced that moistening the freshly cut surfaces revealed a better picture of the ferromagnesian content and helped to decipher the class more correctly. In general the ceiling limit of ferromagnesian minerals for granites coming under 'more or less free of ferromags.' group was taken to be 5-7 per cent.

Since the various rock types are most intimately mixed with one another, it has not been found practicable to delimit the outcrops of these varieties on the geological map separately and their distribution has been marked on the map by a system of hachures and symbols. Special textural features such as porphyritic nature, wherever found, have also been marked on the map by symbols. An attempt has also been made to mark the distribution of the inclusions on the map as far as possible. For this purpose distinctive hachures or colours have been used for large inclusions of granulites, schists and limestones, and the smaller ones and those of other types have been marked by a common symbol of black circle.

An endeavour has also been made to record all possible joint directions. With a view to avoid crowding on the map these have been marked on tissue papers on which the corresponding parallels of latitude and longitude have been traced and which can be made to overlap the geologically coloured sheets whenever required.

Working on these lines our parties have so far mapped an area of about 3000 sq. miles of the massif on one inch to a mile scale, lying between latitudes 24°30′ and 25°30′ North and longitudes 78°15′ and 80°0′ East.

MEGASCOPIC ACCOUNT

Granites: Of the different varieties of granite met with in the area, those with abundant pink felspars form the dominant types. The grey varieties are rather subordinate and in most cases they occur only as local variations. Sometimes the rocks may bear both pink and grey felspars representing a sort of intermediate stage. Amongst the pink varieties, the coarse-grained granite with ferromagnesian minerals and the medium-grained granite poor in ferromagnesian minerals are the two dominant types, the former being slightly more in abundance than the latter.

It has already been stated that the colour of the felspars may be either pink or grey. It is striking to note that there is considerable variation even in the shades of the pink, there being a number of hues including light pink, dark tan, brown and red. Occasionally even a single large sized crystal of felspar shows varying shades of colour in its different portions. In some large crystals of grey felspar the pinkish colour may be seen evenly distributed throughout the whole grain or it may be present in the form of fine threads along certain planes (mostly cleavage planes). Then again the grey felspar may sometime bear a rim of pink felspar.

It has already been mentioned earlier that the ferromagnesian contents of these granites vary considerably. Even in the 'with ferromag.' group the percentage of ferromagnesian minerals varies considerably from place to place. Varieties which are poor in ferromagnesian minerals have their dark minerals scattered here and there in the form of small clots, specks or granules. The finer grained varieties are predominantly felsic in their composition and are somewhat quartzitic in appearance.

With the development of the large sized crystals of felspars as phenocrysts (? porphyroblasts) the rock assumes a porphyritic (? porphyroblastic) texture. It has been noticed at several places that the medium-grained granite, with the development and gradual increase in the number and size of the felspar phenocrysts passes into the coarse-grained group. It may be mentioned here that in most of the coarse-grained granites it is mainly the felspar which is more than five millimeter in size while the rest of the constituents, in general, are much smaller. The phenocrysts of these varieties are invariably greyish pink in colour and are from 35 mm. to 60 mm. in size. These felspars have often been noticed to include the ferromagnesian constituents. At some places the granite exhibits a linear structure developed through parallel orientation of felspars and ferromagnesian constituents, in a direction varying from ESE-WNW to ENE-WSW. Occasionally a well developed foliation in the same direction is impressed on the rocks giving rise to a granitoid gneiss.

Apart from the above mentioned varieties of granites, occasionally a pegmatitic variety is also present in the area. This variety generally occurs in the form of veins, that may be vertical or horizontal in their disposition or may form patches of varying dimensions. It is however very striking that true pegmatites are more or less absent in the region.

The granites, especially of the coarse-grained variety are seen to be crushed locally. Where the crushing has been of higher grade a schistose structure is developed resulting in the formation of a number of mylonitic schistose bands of varying sizes. In extreme cases of mylonitisation, accompanied with coalescence the foliation disappears and a compact vitreous cherty looking rock is formed in the form of bands which vary from thin veins hardly four inches across to large bands forming a great part of quartz reefs.

The granites bear a very large number of inclusions of various types of rocks which include hornblende- and chlorite-schists, quartz-schists, felspathic-schists, granulite, quartzite etc. A detailed account of these has been given separately.

All the different varieties of granites described above are considerably jointed. It is however noticed that only in very few cases an individual joint plane can be traced over any considerable distance. The degree of development and the nature of joints in different portions of a single outcrop may vary considerably. Thus in one portion the joints may be straight and clean slit-like and in another portion they may be weak and curved. Often several joints instead of running parallel, tend to converge and although not quite meet together at a focus, come close together within a very narrow range, and then may again fan out and gradually get wider apart.

When the two varieties of granite occur together, the joint pattern may or may not be common to both. In the former case, however, the joints run straight without being affected by the contact between the two varieties. Sometimes, however, it is noticed that in an outcrop where medium-grained pink granite with little or no ferromagnesian minerals and the coarse-grained pink granite with ferromags. occur together, a few joints in the medium-grained granite continue into the coarse-grained variety unaffected by the contact between the two, whereas a few others (from the same set) in the medium-grained granite almost stop near the junction of the two varieties. This, therefore, appears to show that the joints of that particular set have been impressed subsequent to the formation of both medium- and coarse-grained varieties and that all the joints of the medium-grained granite have not continued into the coarse-grained variety, because of the differences in the grain size of the two types.

In general fine to medium-grained granites especially those which are more or less free of ferromagnesian minerals have better developed joints than the coarse-grained granites. In the latter type the joints are fewer in number and are widely separated apart. This is easily understood because the medium- and fine-grained varieties of granite are more compact and coherent in nature than the coarse varieties, specially those rich in ferromagnesian minerals, and are therefore, apt to develop more clean slit-like joints than the other varieties under similar conditions.

Secondary veins of silica and epidote often fill the joint planes. Along some of them there is a thin chloritic lining. It has been further noted that at places where two joint planes meet each other the chloritic linings along them also merge with one another leaving a sort of wedge of granite.

An attempt has been made to record all visible joints and these have been plotted graphically. A study of these graphs has, however, not shown any obvious pattern, possibly because the existing joints are the result of repeated changes that the constituent rocks have had to undergo in their very long history, the exact nature of which is not yet known precisely.

Gneisses: The distribution of gneisses in the area does not show any regularity or pattern. Their outcrops vary in dimensions from small patches, less than a foot in length to larger masses forming fairly big hillocks. They are often found associated with coarse-grained pink granite rich in ferromagnesian minerals. Generally they are medium- to coarse-grained with varying proportions of pink and grey felspars and clots of ferromagnesian constituents showing parallel orientation with high dips. Occasionally, when the foliation becomes rather ill defined, the rock passes into a granitoid gneiss or gneissose granite. Small lenticular inclusions of amphibole-rich rock are often met within the gneisses, their long axes being oriented along the direction of foliation of the latter.

Banded and streaky varieties have also been observed but are subordinate in occurrence. When present, they have well developed mafic folia formed mainly of varying proportions of biotite and hornblende. The leucocratic bands are mainly formed of quartz and felspars and are at places even pegmatitic in texture. Occasionally the banded gneisses exhibit small scale folding, the axes of the folds invariably following the foliation direction of the gneisses.

The foliation in the gneisses varies from NE-SW to ESE-WNW, with invariably high dips, that may be towards either side. In the southern part of the massif so far covered the prevailing foliation direction is along NE-SW whereas in the northern part it varies from ENE-WSW to ESE-WNW, the latter being more prevalent. At a number of places folded structures are discernible, the axes of the folds generally trending along ESE-WNW, and occasionally plunging at an angle of about 25° towards WNW.

Mutual Relationship: Having briefly given the megascopic account of the different varieties of granites and gneisses, I now turn to the mutual relationship between them. In this connection it has already been mentioned that the different varieties of granite occur most intimately mixed with one another and for this reason it has not been possible to mark on the map any junction lines between them. The markings of the distribution of the different varieties by symbols on the map was planned in the hope that a study of their distribution might reveal some pattern or order in their occurrence. This hope has however been belied and although we have covered fairly extensive ground no rhythm or order has yet been found in their distribution, either in the region as a whole or in any part of it. It may be emphasised here that although occasionally one may come across a fairly extensive outcrop of a single variety, frequently enough more than half the number of varieties enumerated above may be present within a short span of say one hundred yards only. The passage from one variety to another is sometimes gradational whereas at others it is rather sharp. In general however, gradational transitions are frequent. When the two adjacent varieties have allied mineral composition and differ mainly in their texture, the transition from one to the other is generally imperceptible. Occasionally a porphyritic variety represents an intermediate stage. The transition between the varieties rich in ferromagnesian constituents and those that are poor in them is in most cases comparatively sharp. In some vertical sections it has been noticed that there is a tendency for the coarseness in grain size to increase from bottom upwards. Sometimes the coarse variety is found overlapping the fine-grained variety. Another significant feature is the repeated alternation of fine- or medium-grained pink granites poor in ferromags. and the coarse-grained pink variety with a fair amount of femic minerals, in a vertical section. This point has been brought out very emphatically from a study of the logs of a large number of drill holes driven upto a depth of about 75 ft. from the surface, in connection with the construction of Mata Tila (25°5′ 45″ :78°22′ 30″) dam, that have been available to us for examination. The contacts are gradational though the zone of gradation is limited to an inch or so only. Although genetic considerations will be taken up at a later stage it may not be out of place to mention here that considerable alternation in the grain size at rather short depths would be difficult to explain if we were to regard the massif to have been formed from the cooling of a batholith. Another interesting feature is the presence of one variety of granite forming a thin crust, hardly an inch or two thick, over another variety of granite. It is obvious that if the erosion had extended a little deeper, the variety forming the crust would have been completely denuded away leaving the other variety to form the surface of the outcrop. A scrutiny of cases of this type shows that it is either the medium- or fine-grained pink granite poor in ferromags. that occurs over the coarse-grained pink granite with ferromags. or vice versa. Linking this observation with the one made earlier viz. that these varieties are found to occur alternating in vertical sections it is apparent that the occurrence of thin crusts of one variety over the other is merely an erosional feature and is the result of the weathering of masses which initially had alternating bands of these two varieties of granite.

Enclaves of one variety of granite in another type form a common feature in the area. Except for the grey varieties which are themselves very subordinate and therefore not frequently met with, enclaves of one pink variety in another have been observed in all possible combinations, and there is no pink variety which has not been noticed to occur as an enclave in other pink varieties. In all such cases it is noticed that the medium- or fine-grained granite, as the case may be, is considerably more jointed than the coarse one. They may even have different sets of joints.

A mention must also be made of the presence of pink colour along some of the joint planes in grey granites. This colour fades out within an inch or two across the strike of the joints.

The relationship between the granites and gneisses, is also found to be very close and intimate. Enclaves of one within the other are quite frequent. Furthermore inclusions of the granite within the gneiss may in their own turn, include masses of gneiss, and the foliation direction of the enclosing mass may be the same as that of the one that is enclosed. The contacts between the granites and the gneisses may be either sharp or gradational. In the latter case the zone of gradation, is usually very small and may be limited to an inch or two only. Sometimes the granitic material may be seen somewhat penetrating into the gneisses all along the contact. In some places the granite possesses a coarse type of gneissosity, the foliation direction of which is the same as that of the adjacent gneiss.

In some places bands of varying thicknesses of medium- and fine-grained pink granite more or less free of ferromagnesian minerals, are found running along the foliation direction of the gneisses whereas in others they may run across the foliation direction without affecting the gneissosity. In some instances a few fairly wide bands of the granite are seen to alternate with the gneisses, and a faint foliation conformable with that in the gneisses is discernible in them.

It may also be noted here that the distribution of the gneisses in the area does not appear to form any pattern, although they appear to be concentrated along certain zones.

PETROGRAPHIC ACCOUNT

The granites, in general, are formed essentially of quartz, felspars, a few ferromagnesian minerals and some accessories. The felspars present include orthoclase, microcline, perthite and plagioclases. In the porphyritic varieties the phenocrysts are usually of microcline or perthite. Hornblende, biotite and chlorite are the most common ferromagnesian minerals, while the accessories include apatite, iron-ores, sphene, epidote, and zircon.

All the constituent rocks in the massif have been found to exhibit cataclastic effects such as bending and breaking of the twin lamellae of the plagioclase felspars, bending of the biotite flakes, crushing of the component minerals and strain shadows in quartz etc. Some of the minerals such as sphene, and magnetite are present as released minerals. Some quartz is often produced at the orthoclase plagioclase contacts thereby producing myrmekitic texture. Some of the other common textural features observed in these rocks include the presence of patchy and bleached chlorite, scattering of biotite flakes all over in a sort of poikilitic fashion, the occurrence of granules of epidote scattered sporadically all over, the presence of grains of magnetite in large quantities associated with either hornblende or biotite as released mineral, and the presence of sphene, epidote, apatite, magnetite, chlorite and flakes of biotite as inclusions in felspars.

Quartz occurs both interstitially as well as inclusions within other essential minerals. The outlines of quartz are almost always embayed. The grains of quartz found as inclusions within the felspars often show smooth rounded margins. In several cases the mineral shows strain effects.

Although in hand specimens the distinction between the grey and pink felspars is very outstanding, under the microscope no such distinction is apparent and all the varieties contain plagioclases, orthoclase, microcline and perthite. Amongst them two generations are distinctly noticed. The felspars of the earlier generation are found to be much clouded while those of the later generation are comparatively fresh. The former group includes plagioclases and the latter the potash felspars and perthite. The degree of clouding in the plagioclase felspars varies from grain to grain. Twinning is common but zoning is practically absent.

The extremely clouded nature of the plagioclases makes it difficult to determine their exact composition. However, on an average it varies between albite and oligoclase. Their contacts against quartz and potash felspars are irregular and embayed. Often enclaves of potash felspars are also present in the plagioclases. Orthoclase along with microcline is present in fair quantities, though, the former is comparatively subordinate. Their margins are usually corroded or embayed ; and they often form projections into the groundmass. They also commonly bear inclusions of earlier plagioclases and quartz. It appears as though their crystals have grown outwards replacing the groundmass and the adjoining minerals.

Perthite is a fairly common constituent of these granites, forming 11 to 23 per cent of the rock. Orthoclase or microcline are the host minerals in which blebs of albite are present. These blebs are mostly of stringlet, string or rod types. The composition of perthitic large crystals is found to be Or 74 Ab 26. The albite blebs are of a regular and uniform nature, with a common optical orientation, and show simultaneous extinction, under crossed nicols. These blebs exhibit little or no alteration. In some of the thin sections of coarse-grained granites they have been found slightly altered but in those of the medium-grained granites they are invariably fresh. The contact margins of these perthite grains near plagioclases and quartz are commonly embayed and corroded. They have been found encroaching upon their neighbours and also in their own turn are penetrated by other felspars.

Amongst the ferromagnesian minerals present in these rocks biotite is the most common constituent. It is of two varieties, one showing pleochroism from straw yellow to dark green and the other from straw yellow to dark brown with high absorption. The latter variety is more common. There is no directional orientation of the biotite flakes. They characteristically occur as pseudomorphs after hornblende suggesting their formation through the resorption of the former mineral. Magnetite is the most common inclusion, though grains of ilmenite, sphene, apatite epidote, and zircon may also be present. Small pleochroic haloes are seen around zircons.

Most of the hornblende having been altered into biotite and chlorite very little original amphibole is to be seen in these rocks. It is frequently bleached. Inclusions of quartz and iron-ores are specially common.

Chlorite is present in almost all the specimens in some quantity or the other. It is developed by alteration from either hornblende or biotite. The mineral is usually light green in colour with pleochroism from colourless to light green. Some of it is of the pennine variety.

Amongst the accessories sphene occurs in the form of wedge shaped crystals or as granules scattered all over. It is invariably associated with biotite, hornblende or chlorite. Magnetite and ilmenite almost always occur in association with hornblende, biotite or chlorite and appear to have been formed through resorption. Apatite in accessory amounts occurs either as tiny slender needles or as stumpy prismatic crystals. Two varieties of epidote are to be found; one is greenish in colour with some pleochroism, and the other is a colourless variety. Occasionally zircons have been found in association with biotite and they often show pleochroic haloes.

Zircons from the coarse-grained porphyritic pink granite were separated by means of bromoform. They show wide variations in size, zoning, and elongation ratio. Length and breadth measurements of about three hundred grains were made and it was found that about 60 per cent. of grains have a length: breadth ratio more than 2:1 and only in about 40 per cent. the ratio varies between 1:1 and 2:1. The length of the grains were plotted against their width and the scattered diagram so prepared shows that grains more than 0·15 mm. in length have a tendency to be narrow and elongate. A few such elongated grains show rounded ends which on close scrutiny reveal the presence of small irregular crystal faces. Smaller grains are rather stumpy and quite frequently irregular pyramidal and pinacoidal faces are developed on the extremeties.

Modal Analysis:—Modal analyses of a large number of specimens of granites have been carried out and averages have been determined for seven different varieties of granites, which are given in the table on the next page. A study of this table shows that the rocks of this massif range from granite to granodiorite in composition, the predominance being of the granodiorite group. The amount of plagioclase felspars present in the different varieties is fairly high, varying between 21 to 37%. The percentage of the potash felspars varies from 5 to 16%, while that of the perthites ranges from 11 to 23%. The amount of quartz present is around 30%, the minimum being 23% and the maximum 32%. In the varieties bearing ferromagnesian minerals the total quantity of femic constituents varies from 5 to 13%, whereas in the varieties which are deficient in ferromags. the corresponding figure varies from 1 to 2%.

INCLUSIONS

While describing the megascopic and field account of the granites it has already been stated that they include a very large number of inclusions. These are of various types of rocks which include (1) Hornblende —and chlorite-schists, amphibloites and allied rocks (2) Quartz-schists and felspathic schists (3) Granulites (4) Quartzites (5) Quartz-magnetite rocks (6) Slates (7) Sandstone and (8) Limestone.

TABLE SHOWING AVERAGE MODAL COMPOSITION OF GRANITES FROM BUNDELKHAND.

	1	2	3	4	5	6	7
Quartz	23·91	28·94	26·88	31·33	32·87	30·03	31·78
Potash felspars	12·69	12·86	16·79	12·70	5·71	23·21	11·70
Perthite	14·84	13·35	12·09	20·69	23·44	11·48	23·11
Plagioclase	36·36	29·66	37·51	21·03	33·30	32·36	32·00
Biotite	5·11	6·94	3·70	10·07	2·64	0·85	0·11
Hornblende	3·34	3·11	0·11	—	—	—	0·09
Chlorite	3·02	3·32	1·38	2·22	0·23	1·55	0·81
Iron-ores	0·49	0·23	0·55	0·24	1·56	0·39	0·11
Sphene	0·03	0·48	—	1·30	0·23	—	—
Apatite	0·02	0·09	0·01	0·09	0·05	0·04	0·01
Epidote	0·06	0·26	—	0·21	—	—	0·12
Zircon	—	0·03	—	—	0·07	0·09	—

1. Coarse-grained granite with dominant pink felspars and bearing ferromagnesian minerals (Average of 12 analyses).
2. Coarse-grained granite with dominant grey felspars and bearing ferromagnesian minerals (Average of 6 analyses).
3. Medium-grained granite with dominant pink felspars and bearing ferromagnesian minerals (Average of 6 analyses).
4. Medium-grained granite with dominant grey felspars and bearing ferromagnesian minerals (Average of 6 analyses).
5. Medium-grained granite with dominant grey felspars and poor in ferromagnesian minerals (Average of 6 analyses).
6. Coarse-grained granite with dominant pink felspars and poor in ferromagnesian minerals (Average of 6 analyses).
7. Medium-grained granite with dominant pink felspars and poor in ferromagnesian minerals (Average of 6 analyses).

Hornblende- and chlorite-schists etc.:—The inclusions of this type are by far the most common. They vary in size from less than half an inch across to as large as 25 ft. × 10 ft. and sometimes even assume the size of small hillocks. The frequency of these bodies is highly variable. Sometimes within a small outcrop measuring a few feet across they may be present in a cluster of ten or more, whereas at times no inclusion may be observed over a few furlongs of intermittent outcrops. The direction of the foliation of the inclusions is highly variable, as also that of their maximum length, although in some cases neighbouring inclusions are found to have a common orientation. Some times the inclusions are rounded, ovoid or spindle-shaped whereas in others they have a very irregular shape, arms of the included rock interdigitating into the granite, forming a complex pattern. Their margins may be either sharp or gradational. In the latter case the rocks are obviously under conditions of partial digestion. Masses showing various stages of digestion have been found to occur. Where digestion has advanced far enough, the inclusions look more or less like medium-grained granite with somewhat extra abundance of ferromagnesian minerals or rather dioritic in composition. In such cases their identity is recognisable only through smaller grain size and slightly darker colour caused by the excess of the femic constituents. If the digestion had advanced a little further, the inclusion would have assumed the composition of true granite. (This would possibly explain the absence of numerous inclusions in medium grained granites rich in ferromagnesian minerals.) In some cases large crystals (? porphyroblasts) of pink felspars are found developed within the inclusions, which are similar to those found in the adjoining granite, and occasionally small granitic masses are found enclosed within the core of the inclusion itself.

The inclusions of this type are abundant in the coarse-grained granites rich in ferromags. ; in other varieties particularly the fine-grained varieties they are comparatively rare.

Quartz-schists and felspathic schists:—The second type of inclusions are those of quartz-schists and felspathic schists. Their sizes vary from a few inches across to as much as 20 ft. × 100 ft. Their contacts with the enclosing granite may also be sharp or gradational. Usually the granite near the contact shows some sort of lineation which is invariably parallel to the foliation direction of the schist. An interesting occurrence of an inclusion of this type in the coarse-grained granite with ferromags. has been noticed in the Sadhni Nadi, about 6 furlongs NNW of Basatgawan (24°57′ : 79°10′45″) which shows branching towards its northern end, one of the branches gradually curving through as much as 70° from the original direction.

In an outcrop about 50 yards west of Gairwar fort (21°51′ : 79°25′30″) it is noticed that the felspathic schist, in its own turn, is found to bear several small masses of granite, as though the latter have been somehow caught up within its fold.

Inclusions of quartz-schists are more commonly associated with the medium to coarse-grained rocks with pink felspars and ferromagnesian minerals.

Granulites:—The granulites occurring as inclusions in the granites are compact and medium-grained rocks, their colours varying from light to dark grey. These inclusions are commonly associated with medium- and fine-grained granites. Usually their size is small ; occasionally, however, masses of considerable magnitude have also been noticed. In places this rock shows a peculiar weathering, in which closely spaced shallow depressions are developed that are separated from each other by thin ribs standing in relief, recalling honey-comb structure.

Quartzites: Small masses of pinkish grey and greyish white quartzites have been met with included in the granites at a number of places. The quartzite may be either massive or well bedded. The latter type is, however, more common. Usually they occur in the form of bands, the width of which varies from a few inches to as much as 10 ft. and the length from a foot to about 20 ft. Only in one case it is large enough to form a small mound.

Quartz-magnetite rock: It is a hard fine-grained compact rock which is dark brown in colour, and is found associated with coarse-grained pink granite with ferromags., and also gneisses. More often, however, it has been found to form isolated outcrops and it is not possible to precisely fix the association. Its occurrence is particularly more abundant in the country to the west of Mauranipur (25°15′ : 79°9′) in Jhansi district. It may not be out of place to mention here that close to this locality there is a large inlier of (?) Dharwarian schists, and it is likely that the above mentioned inclusion of quartz-magnetite rock may have been originally associated with the same.

Slates: Inclusions of slaty rocks have been met with only at one place about three furlongs NE of Nadgaon (24°48′ 45″ : 79°26′ 45″) in the Chhatarpur district. There are two small outcrops there which are about

25 yards apart from each other, the intervening area being covered with scree. It is likely that these two are parts of one and the same larger mass. It is unfortunate that the contact between the slates and the granites is obscure.

Sandstone: An isolated occurrence of inclusions of sandstone has been found in the granites in the Mangrar valley, about 1¾ miles ENE of Balgain (24°36′30″; 79°24′). Unfortunately the masses of granite in which these inclusions were observed are not quite in situ, instead they are lose blocks. However, their size is so large, and shape so angular that there is no doubt whatsoever that they must have originated from a close source.

The sandstone inclusions were found in two blocks of granite lying adjacent to each other. In one case a band of sandstone about 1″ to 1¾″ thick runs right through the whole block of granite as though it was sandwitched within the latter. The overall dimensions of the sandstone are 22″ X 1¼″. The granite is of medium grained type bearing little or no ferromagnesian minerals.

In the second case small inclusions of sandstone are seen on the surface of a granite block which is lying very close to the one described above. At first sight it appears as though these inclusions were merely sticking superficially to the granite mass. But a close scrutiny reveals that not only that the sandstone is included within the granite, smaller masses of the latter itself are also enclosed within the former, leaving no doubt about their mutual relationship.

The sandstone is brownish in colour and is medium-grained in texture. It is characterised by grains of more or less uniform size. Its contact with the granite is fairly sharp though in certain portions it appears to be grading faintly. It is, however, not clear as to how it has been left unaffected by the numerous changes through which the rest of the country has undergone.

Limestone: The limestone that has been met with as inclusions in the Bundelkhand granite country is either white, yellowish or pinkish in colour. It is interesting to note that the limestone, in its own turn is found to bear inclusions of granite. The outcrops of limestones met with near Gairwar (21°51′:79°25′30″) are roughly 100 to 200 yds. long each, and their estimated thickness is about 20 to 25 ft. About half-a- mile SW of Gairwar, a small outcrop of granite has also been noticed near the top of one of the limestone hills. It is, however, interesting, that neither the granite shows any striking chilling effects on its margins nor the limestone shows any feature attributable to contact metamorphism.

QUARTZ REEFS

A very marked feature of the Bundelkhand granitic terrain is the presence of a number of parallel quartz reefs that form prominent narrow ridges. They run discontinuously for long distances which may be as much as 18 miles in some cases. By far a vast majority of them pursue a more or less common direction that varies from NNE-SSW to NE-SW. A few deviations from this general trend however are also observed. Occasionally the reefs locally show slight curves or sharp swings in their strikes. Sometimes they give out small offshoots and in a few instances several reefs coalesce into one. Faulting with small displacement is not unusual.

These reefs are highly jointed, three sets of prominent joint planes being discernible. The most dominant plane usually trends along the strike of the reef and is invariably dipping at high angles which may be towards either NW or SE. The second set of joints runs in a NW-SE direction being almost at right angles to the former. The joint planes of the third set usually bear a small angle to the horizontal plane, the value of which has been found to be considerably varying. In some reefs the joints of this set are so well developed and closely spaced that they impart a bedded appearance to the rocks. In some reefs a deep reddish brown ferruginous staining is developed along the vertical joint planes. Smears of chloritic matter are also observed though only rarely. Occasionally imperfect dendrites are also seen.

The reefs are generally covered with debris on their flanks and the contacts with the country rock are rarely observed. Wherever seen, the adjoining rocks show slight effects of crushing. A number of thin quartz veins are also common in the adjoining country rock, which may often be irregular in their strike but generally follow or make a small angle with the general direction of the reef.

Occasionally the pink granites stretching to about a mile on either side of the reef show a foliated structure, the direction of foliation being parallel to that of the strike of the reef. The granites occurring between the two coalescing reefs are highly fractured and occasionally in these regions a schistose structure is impressed on them, the direction of the schistosity being the same as that of the strike of one of the reefs. Faulting on a small scale is frequently discernible in these schistose rocks.

A close examination of the reefs reveals that their rock is of a composite nature, the most abundant constituent being a fine-grained compact cherty material of pinkish to greenish grey colour, with which is associated some milky quartz. The latter occurs in the form of veins which are usually not so well defined and may ramify all over. Sometimes they seem to show a regular trend in a NNW-SSE direction. These veins or vein-like masses possibly represent a later phase of silicification. In places the milky quartz becomes more prominent, subordinating the cherty material. Occasionally angular patches of the latter are seen embedded in the milky quartz thereby imparting a brecciated appearance.

Under the microscope the cherty material of the reef is found to be made up of angular to subangular grains of quartz, with small quantities of microcline, perthitic felspar and plagioclases. A few clots of green pennine chlorite are also present and small grains and sheafs of magnetite are associated with it. The chlorite appears to have developed after biotite. The plagioclases are usually saussuritised and their twin lamellae are displaced. In extreme cases the rock is almost crushed and is formed essentially of fine granular aggregate of quartz with very subordinate quantities of felspar and a small amount of scattered magnetite. The cataclastic structure is very prominent.

Occasionally in those parts of the reefs where milky quartz is absent or is very subordinate, a schistose structure is discernible in the cherty rock, the direction of foliation being the same as that of the strike of the reef. Small amounts of pyrophyllite are found associated with this schistose rock. This is a very interesting feature and I propose to defer a further treatment of this subject to a later stage (see page 16).

The quartz veins that ramify the cherty rock are generally quite thin. Their grains are anhedral and the texture is from medium to coarse. Sometimes well formed crystals of milky quartz are seen growing from the margins of the veins, which may occasionally be so developed as to assume the form of geodes. Platy quartz is also observed at a few places.

The unaltered schistose cherty rock of the reef resembles both lithologically and structurally the mylonitic schistose bands that are observed associated with the granites and gneisses. In the marginal parts of some of the mylonitic bands the foliation splays out in the granites in opposite directions indicating thereby, some sort of slipping movements along these planes. Occasionally there are narrow zones, not exceeding fifteen feet in width, in which thin vein like bands of mylonitic schists are seen traversing in various directions, the direction of the schistosity as a whole however remaining along the general strike of the reef viz. NE or thereabouts. It is noticed that in contrast with this the mylonites associated with the gneisses and gneissose granites usually cut across the foliation of the latter.

Thus it appears that the movements responsible for the formation of the mylonitic schistose bands had occurred at a stage later than the formation of the gneisses and granites. The cataclastic and the granulated nature of the cherty reef rock together with the presence of schistose structures greatly suggest that the reefs represent long narrow zones along which intense mylonitisation had taken place.

BASIC DYKES

A number of basic dykes also intrude through the granite massif. By far a vast majority of them run in the direction NW-SE, which is almost at right angles to the prevailing direction of the quartz reefs. Some of the basic dykes, however, have slightly different directions, ranging from E-W to ENE-WSW.

The composition of these dykes, in general, is doleritic showing typical ophitic texture under the microscope.

With regard to the relative age of these basic dykes and the quartz reefs, it is noticed that, although the two do not come in contact with each other frequently, a few instances have been observed when the latter appear to have cut across the former. It is thus inferred that the basic dykes are younger than the quartz reefs.

Taking the quartz reefs and the basic dykes both into consideration, one is struck with the problem as to what was the controlling factor that determined the direction of these two types of dykes. It is worthwhile noting that, in general, the directions of the strike of these systems of intrusives are also the commonest directions of the joint planes in the granites. Ordinarily an intrusion is apt to follow the planes of weakness of the host rock. In spite of the fact that the granites possess two or more sets of joint planes, the quartz reefs have stuck to only one direction, and the dolerite dykes pursue the second. This situation is very intriguing and is difficult to answer. One may perhaps infer that at the time of intrusion of the quartz reefs only one set of joints, viz. those along NE-SW direction, was well developed, and the reefs were formed in that direction. Subsequent dynamic activity and associated factors may have caused the development of joints along NW-SE direction and the doleritic intrusives which came later were guided by the planes of weakness in this direction.

TUFFACEOUS SERPENTINE-CALCITE ROCK

In addition to the doleritic dykes mentioned above, a very interesting find in this area has been that of a tuffaceous serpentine-calcite rock, in a nala bed, about 6½ furlongs NE of Angor (24°44′:79°25′ 30″), in the Chhatarpur district of Madhya Pradesh (old Vindhya Pradesh). Both lithologically and under microscope this rock is identical with what has been described hitherto as the diamondiferous agglomeratic tuff of Majhgawan, Panna. In that region, however, the prevailing country rock belongs to the Vindhyan system. This is thus the first find of this rock in a purely Bundelkhand granite country. There are no younger rock formations within a radius of 9 miles from this outcrop. The nearest exposure of granite also is about 170 ft. away. The contact of the rock with the granite being completely masked, its relationship with the latter remains obscure. One may, however, confidently regard it to represent an intrusive into the granite.

This ultrabasic rock is exposed for a distance of about 250 ft., and the maximum width of the outcrop is 42 ft. The rock is greenish in colour and is dissected by a network of calcite veins. On a freshly broken surface the greenish matter shows some fragments of dark colour. Under the microscope this greenish matter is composed of mainly serpentinous material which has different shades of green colour. Small crystals of antigorite and cross-fibre veinlets of chrysotile are also recognisable within the serpentinous mass. Besides that, some flakes appearing to be of phlogopite mica are also present.

The granite in the vicinity is dominantly of a coarse-grained pink variety. It may also be mentioned here that a rock reported by local men to have been met with in a well situated about 190 ft. to the SW of this tuffaceous serpentine rock locality, is a basic dyke like rock. The pieces in the dump of the material excavated from the well are highly weathered. They are, however, rounded blocks of earthy material of the type seen in a weathered basic dyke elsewhere.

It has, however, yet to be proved whether the tuffaceous rock near Angor is diamondiferous or not.

MINERALISATION

A very outstanding feature of the Bundelkhand granite massif is the absence of any large scale mineralisation. Although traces of malachite, azurite, covellite, pyromorphite and small quantities of galena have been reported from some of the quartz reefs and small encrustations of molybdenite have been observed along fracture planes in some medium-grained pink granites poor in ferromagnesian minerals, no deposit of any substantial size has so far been brought to light. Numerous quartz veins of massive dimensions run for miles across the granites, yet not one instance of a true pegmatite has been observed anywhere, and there is a total absence of minerals like mica, beryl, tourmaline etc. that are associated with that phase of igneous activity. The only mineral which occurs in somewhat workable quantity and of sufficient purity is pyrophyllite which occurs associated with quartz reefs and forms bands, lenticles or pockets. The mineral has been known to the local inhabitants for a very long time and on account of its resistance to chemicals and ready amenibility to dressing it has been used for making pots since very ancient days. A small cottage industry for making pots of various shapes and sizes exists near deposits of good quality e.g. at Gorahari, Kaligawan, Dhankua in Uttar Pradesh and at Khaira and Sarkani in Madhya Pradesh. Of these, the deposit at Gorahari is well known and has been worked to a considerable depth below the surface without any deterioration in quality.

The pyrophyllite occurs in the form of lenticular bands which trend along the strike of the quartz reef, with which is associated quartz-pyrophyllite-schist. Small clots of chloritic matter are occasionally observed. From Hamirpur, Misra and Sood (1947) have recorded the occurrence of well developed crystals of diaspore which show a prominent bladed structure and occur as nodules in association with pyrophyllite.

Thin smears of green soft pyrophyllite have been observed developed along some joint planes in the quartz reefs in close vicinity of pyrophyllite pockets. Another interesting feature noticed in this connection is that some of the felspars in some granite adjacent to pyrophyllite bearing quartz veins have been altered to green pyrophyllite and the ferromagnesian minerals have been chloritised. Occasionally small grains of metallic ores are also seen in quartz-pyrophyllite rock. It thus appears clear that certain amount of mineralising solutions have come up along weak zones provided by the quartz reefs and the metasomatic alteration caused by them has given rise to pyrophyllite. Misra (1944) has also come to similar conclusion. This activity was, however, of a very limited nature resulting in an overall paucity of mineralisation. Why this was so limited is a querry which does not seem to have a straight answer. Rocks of similar antiquity elsewhere are considerably mineralised. For some reason the magmas in this region were 'dry'. A suggestion occurs that this 'dryness' may have been due to the fact that the magmas involved were of secondary origin, and were possibly formed by refusion of earlier sediments, and were thus not fully fed from a deep magma chamber.

GENESIS

It may not be out of place to mention here that the subject of origin of granites, in general, has evoked a very large amount of interest amongst the geologists and is one of the most lively topics in our science today. It may be recalled that in the earlier period of the growth of geology a magmatic origin for granites was accepted without hitch or hesitation. Subsequently, however, some of the workers questioned the applicability of this mode of origin for all granites and it was suggested that at least some of them have been formed by replacement of the country rock. The supporters of this view have laid stress on molecular replacement and addition of material. Those of the other group have stuck to the older belief persistently and hold that the granites have been formed by the solidification of the molten magma. There is still a third group that takes an intermediate stand and believes that differential refusion in depth gives rise to a palingenetic magma, and that the homogeneous granites represent injections of a magma of this type, whereas gneissose granites within which relict structures of pre-existing rocks remain result by the intimate soaking and metasomatism of the country rocks by fluids derived from such magmas.

Inspite of all the intensive work on numerous masses of granites no definite criteria have so far been evolved which would be acceptible to all as decisive tests for one opinion or the other. There have been attacks and counter-attacks. For each evidence given by the supporters of one view, there has been an equal and opposite reaction from the other side. The bottleneck with the former, as Buddington (1948, p. 21) emphasises, is the "difficulty in satisfactorily explaining the space problem posed by large batholiths and also the great volume of granitic rock in batholithic masses if they are considered simply as a product of one-cycle differentiation of basaltic magma." For the latter theory he aptly writes that

"that variety of granitisation hypothesis which assumes large scale intermigration of ions or atoms through solid rock, meets a profound difficulty of adequate energy and time." Under these conflicting views, a hesitant mood is apt to be developed and one is tempted to pray for the granites themselves to come forth and speak in the language spoken by the human beings, and thereby settle the dispute. Such a miracle is, however, not likely to happen and we will have to patiently continue to apply our own interpretations to the facts recorded in field and laboratory.

To begin with, the age-old conception of igneous batholithic origin may be applied to the Bundelkhand massif and it may be seen how far it can explain the various characteristic features that have been described earlier. The problem would have been considerably simplified if the batholithic wall rock could be seen at some place. We are, however, set with a natural limitation in this direction, there being complete absence of the wall rock along the boundaries of the massif; on the northern border it is overlain unevenly by the Gangetic alluvium which has left uncovered numerous little isolated tors and hillocks of granite to form so many inliers; on all the other sides the massif is bounded mainly by the rocks of the Vindhyans and Bijawars which rest unconformably over the denuded surface of the granite.

Next the batholith may be characterised by the presence of roof-pendants. In this direction we have some evidence, numerous xenoliths of different types of rocks having been found entombed in the granites that could be interpreted to represent fallen blocks of the country rock through which the batholith made its way. These xenoliths could, however, be also interpreted to represent the relics of original rocks that have been left behind unaltered by processes of granitisation or metasomatism. The structures and textures that characterise these inclusions are capable of being interpreted either way and a caution is needed in coming to a conclusion. In fact a study of some of the xenoliths have led Saxena (1953), Mathur (1954) and Misra & Saxena (1956) to conclude that the granites in which they are lodged are of metasomatic origin.

The heterogeneity in texture and mineral composition of these granites, both on the surface as well as in depth, and sometimes within short spans, appears to indicate that all the varieties of granite met with in this area are not of one single generation. Ordinarily one would expect that the cooling of a magma under plutonic conditions would give rise to a rock type with a more or less uniform grain size, and it is not possible to visualise conditions under which such a wide interdigitation of varying types would result from a single magma. Some of the varieties could certainly be treated as variants developed through changes in environments that may have occurred in the different parts of the massif either in the initial or in subsequent stages, but there are two varieties, viz. the coarse to medium-grained pink granite bearing ferromags. and the medium to fine-grained type poor in ferromags. which must be treated as distinct units. It may, therefore, be inferred that at least these two varieties have not been formed at one and the same time. This leads to the corollary as to which variety came first and what was the subsequent order? An answer to this querry can possibly be sought in the observations on the number of inclusions present in the different varieties of granite. That which came first may be expected to bear a larger number of undigested relics of the roof-rock in the form of inclusions. On this basis the coarse-grained pink granite bearing ferromags. may be treated as the older one. This observation, is, however, offset by another feature that the enclaves of medium-grained granite poor in ferromags are found abundantly in the coarse-grained variety indicating the possibility that the medium-grained rock must have existed before the coarse-grained type came. The force of this latter argument is, however, considerably weakened by the fact that the enclaves of the coarse-grained granite are also found in the granite of the other variety.

Another feature that has a bearing on this problem is the nature of joints and the amounts of shearing effect shown by these granites. The type showing the maximum cataclastic effects should be treated as the older variety. The evidence in this direction also is not sharp and distinct since the variation in the degree of shearing and cataclastic effects is not so clearly marked. On the whole perhaps the medium-grained granite shows slightly greater amount of shearing etc. The seemingly smaller amount of stress-effects in the coarse-grained granites could, however, also be explained by the fact that the original stress effects in this type of granite may have been obliterated or subdued by the secondary growth of crystals through metasomatism of which there is considerable evidence in the presence of abundant large plates of felspars. This again leaves the matter indecisive. On the whole there is perhaps a slight swing of balance in favour of the coarse-grained granite being regarded as the older of the two.

Be that as it may, considering the magmatic origin for the entire massif it may be visualised that these two varieties of granites were intruded into the country rock one after the other. Such a hypothesis would explain the two important features of textural and mineral variations to a considerable extent. The intimate interdigitation would, however, be still difficult to answer. Furthermore it is noticed that 'windows' of granite are met with in some of the xenoliths. If the latter were roof-pendents caught in the 'batholith', the process of assimilation, commencing from their exterior surface, should progressively diminish towards the core. Under such conditions the development of granite in the interior, with outer portions still remaining unassimilated and undigested, is not explainable, and it becomes difficult to accept these xenoliths as roof-pendants. It may also be noted that although in many xenoliths full developed granite may not be present, porphyroblasts of pink potash felspar of substantial size have got developed, which possess the same characters as those found in the enclosing granites.

Lack of mineralisation and more or less complete absence of late-magmatic activity in the form of pegmatites are some of the other features which throw doubt on a batholithic origin for these granites. In addition there is also the 'room' problem. The massif occupies no less than ten thousand square miles of area and it is by no means easy to understand how such a large amount of magma would be able to make room for its emplacement.

A study of the zircons from these granites also affords a somewhat interesting evidence. It has been stated earlier that 60 per cent. grains of zircon from one of the granites showed a length : breadth ratio of more than 2 : 1, and the rest varied between 1 : 1 and 2 : 1. According to Poldervaart (1950) in granites of igneous origin a majority of zircon grains have the ratio more than 2 : 1. This would place the present granite in the igneous fold. I am, however, inclined to think that the application of this formula needs further consideration. Although it will be accepted at all hands that zircons from igneous rocks, as compared with those from sediments will tend to show a greater length : breadth ratio, it need not necessarily follow that if the majority of the grains possess this feature viz. a greater length : breadth ratio, the rock must be regarded as of igneous origin. It has been observed that zircons can withstand transport over considerable distances without showing any substantial change in their shape and size. So that such sediments as have not had an opportunity to travel over really very long distances before being deposited in a basin are apt to contain substantially high percentage of grains with a greater elongation. A recent study of some of the Gondwana sediments in the Geological Survey of India has revealed the presence of nearly 30 per cent. grains of zircon possessing a length: breadth ratio of more than 2:1. I am, thus inclined not to lay too much emphasis on this evidence, and that overall considerations must be given greater weightage.

It has been shown that many of the megascopic features of these granites cannot be appropriately explained by the hypothesis of plutonic origin. Under the microscope it is noticed that one very characteristic feature of most of the varieties of granite is the presence of felspars of two generations; the earlier ones are very much clouded and the younger ones are fresh and more or less clear. The former are plagioclases and the latter include orthoclase and perthite. The clouding of felspars is generally attributed to contact or thermal metamorphism. Lately, however, it has been suggested that this may be produced as a result of desilication or basification. It can also be due to high energy level attained by the granite at the time of introduction of potash rich solutions. Heating alone without reaching a pneumatolytic phase can give rise to clouding. In view of the fact that the potash felspars present in these granites are unclouded, it is likely that the clouding in the present case has been brought about by the potash rich hydrothermal solutions. In any case, it does indicate the occurrence of 'post-plagioclase activity' either in the form of hydrothermal solutions or desilication (basification).

Another characteristic petrographic feature of these granites is the presence of irregular and embayed margins of crystals of potash felspar, which often develop into very large crystals. They engulf crystals of earlier plagiocalses, blebs of quartz and also grains of some femic minerals. The margins of quartz grains are also sutured.

There is a complete absence of zoning in the plagioclases. Myrmekitic intergrowth is common. Ghost structures are also frequently met with. Felspars are found penetrating into adjoining grains of mica and hornblende. Optical continuity is observed in some cases of crystals which are otherwise separated apart. All these textural features are more in harmony with the replacement origin of granites than with that of magmatic cooling. Working on the granites from a part of this massif near Kabrai (25°24′ : 80°0′) Misra and Saxena (1956) have shown that the granites have been formed by replacement from hornblende-biotite-schists. Working on pyrophyllite that is found associated with the quartz reefs in this area Misra (1944) has come to the conclusion that this mineral is of hydrothermal origin and has been formed by replacement. In our study of pyrophyllite we have also come to the same conclusion.

Thus many features can be explained satisfacteriiy by the hypothesis of replacement origin. But new problems also crop out and demand for an explanation. It has been noted before that a great variety of rocks are found as inclusions within these granites particularly in the coarse-grained pink variety bearing ferromagnesian minerals. Applying the hypothesis of replacement origin to this variety it is inferred that the inclusions represent the relics of the unaltered parent rocks. The obvious corollary would be that such diverse rocks as hornblende- and chlorite-schists, quartzites and quartz-magnitite rock, granulite etc. of which inclusions are found in this variety have been replaced in such a manner that they have all led to the development of a more or less uniform variety of granite. This appears to be an impossibility. Ordinarily it is expected that the compositional differences in the original rocks will also be reflected in the resultant rock. No such indication is noticed. It is, therefore, apparent that although it may be accepted that locally, as at Kabrai, granites have been formed by replacement or metasomatism the entire lot cannot be of this origin. It would thus appear that the entire massif has not been formed by one single process, may it be metasomatism or magmatic intrusion. In each case there are some strong favourable evidences, as well as some weaknesses. It is quite likely that the granites may have been formed partly through intrusion of a magma and partly through metasomatism. Thus it may be treated as a complex massif.

The assumption of two intrusions of magmas formed by anatexis and palingenesis, followed by metasomatism would possibly explain the features in the best possible way, although it is very likely that certain amount of primary magma may also have been available. In fact, in anatexis, as suggested by Sederholm, the presence of certain amount of granitic magma is inherently involved. The idea of palingenetic magma, against primary magma is necessary because it would not only solve the 'room' problem which is very substantial, it also helps to understand the intimate relationship between the granites and the gneisses that is observed in this area. Furthermore the palingenetic magma will also not be so rich in pegmatitic constituents as a primary magma would be, and this would explain the lack of pegmatitic phase in this region. It is thus pictured that initially the area was made up of sedimentary rocks primarily consisting of arkoses, with subordinate quantities of shales etc., which on metamorphism gave rise to gneisses and schists and other metasedimentaries. In course of time some of the fold roots at depth got fused, possibly with the aid of a primary magma, producing anatexial magma or magmas.

Their intrusions occurred in two phases, one being granodioritic in composition and the other adamellitic. The former gave rise to the varieties of granites bearing ferromagnesian minerals, and the latter to the varieties free of femic constituents. This was followed by hydrothermal activity which caused metasomatism. During this phase the plagioclases got clouded and were partly replaced by potassic felspars. The quartz reefs came as the closing phase of the igneous activity. The whole massif was then subjected to tectonic movements which sheared the reefs, and the granite and gave rise to the mylonitic schist bands within the coarse-grained pink granites. Probably some gneissosity was also impressed on the granites at this stage. To complete the picture the basic dykes came as the last stage.

This is only an approximate picture of the more important events. Through this assumption we can explain most of the features that characterise this massif. The immense mineralogical and textural variation is due to the several phases of activity in the area. The two dominant groups of granite in the area are granodioritic and adamellitic in composition, each representing one phase of intrusion. The intimate mixed nature of the granites is due to the fact that two phases of intrusion occurred at such short interval that the earlier phase was still plastic when the latter phase came and allowed the younger one to penetrate freely into the earlier and thereby caused to form numerous enclaves of one type into the other. The absence of regularity in the distribution of the granites is due to there having been several phases of activity which included two intrusions and metasomatism, the effect of the latter being variable from place to place. The large nature of the pink felspars in the coarse-grained granite bearing ferromagnesian minerals is due to their metasomatic origin. The cataclastic effects in all the varieties have been caused by later tectonic movements. The plagioclase felspars got clouded during metasomatism and also during later stresses and strains. The formation of perthites, which are of exsolution type, is explained by assuming that the original potash felspar, that was formed by metasomatism, had enough sodic content, which got released in the form of albite blebs when the mineral was subjected to later stresses and strains.

AGE AND CORRELATION

Finally the question of the age of these granites and gneisses and of their correlation with other granitic rocks in the country may be considered. Based on the assumption that they are pre-Aravalli and pre-Dharwar, these rocks were for long regarded to be the 'oldest rocks' of the country. The existence of a large number of inclusions of a great variety of rocks within these granites has, however, conclusively exploded this conception and one may with absolute confidence assert that these are certainly younger than the metamorphics represented by the inclusions. A study of the latter tends to show that they may be regarded as Dharwar metasediments. The size of the inclusions, in general, is so small and they are so far detached from other occurrences of Dharwar rocks in the country that it would be difficult at this stage to conjecture with any degree of certainty as to what stage of Dharwars they may belong to. In any case it is definite that the granites are younger than at least the oldest of the Dharwars.

With regard to the upper age limit it may be noticed that the oldest formation that has been met with overlying these granites belongs to the Lower Bijawar series and it is, therefore, inferred that the granites and gneisses are necessarily pre-Bijawar in age. It may perhaps be conjectured that there formation is associated with the orogeny of post-Dharwar-pre-Cuddapah epoch. It is interesting to recall here that as early as 1909, Fermor had included the Bundelkhand granites in formations of age subsequent to the Dharwarian folding.

Regarding correlation with other granitic rocks in the country it may be noted that in the Peninsular shield only a small part has been differentiated as granites, the rest being mapped as unclassified crystallines. For purposes of correlation Fermor (1936) classified these crystallines into two groups viz. (i) Charnockitic and (ii) non-Charnockitic. In the latter group he formed Bundelkhand type as a unit and included within it the rocks from (1) Bundelkhand (2) Satpura-Ranchi (3) Shillong Plateau and (4) Hyderabad.

In addition to the areas enumerated above, the basement igneous rocks of Rajasthan have also been correlated with the Bundelkhand granites and gneisses of the type area by Heron.

In general, two distinct types of granitic rocks occur in peninsular India. One of these consists of true gneisses showing distinct gneissose banding and the others are more or less granitic in texture. It is noted that the rocks of the latter group show distinct intrusive relationship with the former in all the regions except in the type area of the Bundelkhand granites, where the gneisses are very subordinate and their mutual relationship is somewhat obscure.

A comparative study shows that the Bundelkhand granite of the type area bears a fairly close resemblance to those rocks which are more granitic in nature than gneissic and which have been named differently in various regions as Closepet granite, Arcot granite, Bellary granite, Singhbhum granite and Mylleum granite, and it may, therefore, be correlated with them. Krishnan (1956) has also suggested the same. It may, however, be pointed out that except in Rajasthan where a few workers believe that the Banded Gneissic Complex and the Berach granite are older than the Aravallis, the granitic gneisses of all the above mentioned areas are younger than the Dharwars but older than the Puranas. Lately, however, it has been suggested that the granites and gneisses in Rajasthan are younger than the Aravallis. In any case as the picture stands now, it is more suggestive of the fact that Banded gneissic Complex and the Berach granite of Rajasthan may be correlated with the Peninsular gneiss and the Bundelkhand granite respectively, thereby clearing the uncertainty that exists today.

Ladies and gentlemen, I thank you once again for the honour you have done me.

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SECTION OF BOTANY

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PRESIDENTIAL ADDRESS

MOULDS, METABOLITES AND TISSUES

Before I occupy this coveted chair of the Botany Section of the Indian Science Congress, permit me to say 'thank you' to all those who have reposed confidence in my scientific stature and elected me to this post of distinction which is rightly to be shared with my colleagues, past and present, in the Botany Laboratory of the University of Madras. My first duty is to express my gratitude to my teachers from whom I had the initiation into the study of Botany: foremost is the late Prof. B. Sahni, Sc.D., D.Sc., F.R.S., under whose inspiring leadership I remained for well over six years ; the second on that list is Prof. M. O. P. Iyengar, M.A., Ph.D., F.N.I., in whose care I graduated and whose chair in botany I now have the good fortune to occupy. I have also to thank Prof. S. N. Das-Gupta, D.Sc., F.A.Sc., Mr. F. C. Bawden, M.A., F.R.S., and Dr. S. D. Garrett, M.A., Sc.D., who collectively created the spark in me for researches in the field of plant pathology. I would complete this round of acknowledgments by extending my deep appreciation for all encouragement I have received from two distinguished Indian Botanists, Prof. P. Maheshwari, D.Sc., F.N.I., and Dr. R. K. Saksena, D.Sc., F.N.I.

My subject for this address is one of recent origin. It relates to the unfolding of a new vista in scientific thinking where tiny microbes, considered to be almost inert or innocuous, lying intermixed with particles of soil or forming the bulk of aerobiological floras have been shown to possess extraordinary dynamism in their metabolic functions. Thus, we have toxins and antibiotics that have revolutionized man's knowledge of the microbes and enzyme substrates and newer enzyme functions have been discovered in this multitude of microscopic life.

Whilst pure mycological studies are fascinating by themselves, the new concept in the study of enzyme systems and metabolic products of the fungi has opened a new chapter in the physiological functions of plants under the influence of these toxin(s)/antibiotics that these fungi produce *in vivo*. Much of the pioneering work came from the virus pathologists but they were in a more fortunate position in that they have a causal infective agent that had a remarkable rapidity in systemic spread within the plant tissue, a condition not obtainable among the fungi. Nevertheless, the obligate parasitism of the virus does not permit of *in vitro* studies to the extent that the facultative fungi would allow and this undoubtedly lent a helping hand in the development of the new ideas on fungal toxaemia in plants which subject I shall attempt to develop today.

. TOXINS AND ANTIBIOTICS

Many investigators have shown that various micro-organisms are capable of producing diffusible materials which can alter substantially morphological development of fungal hyphae and these morphogenetic disturbances are not followed by any effect on respiration or glycolysis. For instance, the curling factor obtained from *Penicillium janczewskii* Zal., in a pure crystalline form when grown in a synthetic substrate is the same as that obtained from the metabolic product of *Penicillium griseofulvum* Dierckx., and is named griseofulvin. Griseofulvin produces severe stunting of germ tubes of *Botrytis allii* and, indeed, on many other fungi belonging to all the classes of fungi except the Oomycetes and yeasts and this difference was ascribed by Brian (1947) to the basic difference between the two cell walls ; those that responded to griseofulvin by showing morphogenetic disturbances had chitinous cell-walls, whereas the Oomycetes have cellulose walls and the yeast walls were composed of some other polysaccharide. It was further reported that griseofulvin had an inhibitory effect on seed germination of higher plants and retards root extension similar to that of indoleacetic acid and coumarin. A somewhat analogous position is reported with the recent boom discovery—the gibberellins. For instance, the fungus, *Gibberella fujikuroi* produces fusaric acid, dehydrofusaric acid, Gibberellin A and Gibberellic acid, the last two resembling growth substances. Gibberellin A differs widely in its ability to suppress axillary bud formation in peas and is inactive in ordinary Avena tests. It, however, produces seedling elongation in soybeans and leaf culm elongation in rice seedlings. Gibberellic acid which is a derivative of Gibberellin is more pronounced in its ability to cause lengthening of internodes and can do so in many monocotyledons and dicotyledons.

Despite the fact that fusaric acid, a pyridine-carboxylic acid, which occurs as an unsaturated dehydrofusaric acid and a saturated fusaric acid, was isolated over two decades ago by Yabuta, Kambe and Hayashi (1934) from the saprophyte *Fusarium heterosporum* Nees, it fell to the lot of Gäumann *et al.* (1952) to demonstrate unequivocally that the facultative parasites, *Fusarium lycopersici* (Sacc.) Wr., *Fusarium vasinfectum* Atk. and *Gibberella fujikuroi* (Saw.) Wr. (that enjoy a worldwide distribution and are well known for the damage they inflict on crop plants) produced this important wilt toxin. Much literature has accumulated since on the *in vitro* nutritional requirements of these fusaric acid producing fungi and many excellent reviews have appeared on this subject (Gäumann, 1954, 1957 ; Dimond, 1955). Our own work in this field indicates that *Fusarium vasinfectum* and *F. moniliforme in vitro* show differences in their relationships to nitrogen source and sugar consumption, and the reaction of the medium with the growing of these organisms was influenced by the form and source of nitrogen metabolized by them (Srinivasa Pai, 1953). Similar differences in the sources and consumption of carbon have been noticed in *Fusarium lycopersici* and *Gibberella fujikuroi* (Sanwal, 1956 ; Stoll, 1954), and Sanwal (*loc. cit.*) further pointed out that there was an optimum C/N ratio for fusaric acid output by *F. lycopersici*. A somewhat analogous situation exists in the *in vitro* behaviour of *Penicillium gladioli* McCull. and Thom which produces the antibiotic substance gladiolic acid (Brian *et al.*, 1948). This antibiotic is produced under a wide range of culture media and is influenced by a characteristic pH drift ; continued low pH being unfavourable and rapid rise in pH beyond pH 7·0 showing rapid disappearance of the antibiotic. Like fusaric acid this substance also occurs as undissociated molecules and this is at low pH when it is highly fungistatic. At pH 7·0 dissociation of gladiolic acid is complete and it is then almost inactive.

RHIZOSPHERE AND FUNGAL METABOLISM

Much of our work and our familiarity with the wilt toxins has been with fusaric acid, the pathogen *Fusarium vasinfectum* and the host plant, cotton. There seems little doubt that in almost all black cotton soils we have examined, *Fusarium vasinfectum* is present and, indeed Subramanian (1951 a ; 1952 a, b) has given a comprehensive account of 15 species of Fusaria belonging to 6 sections of Wollenweber's system of classification of this genus. He also recorded several varieties and forms of *F. vasinfectum* Atk. (Subramanian, 1951b) and although these forms showed morphological similarity, they had variation in growth rate and pathogenicity on cotton, a fact connoting to their occurrence in Southern Indian soils in a multiplicity of forms and not as a single 'wild type' as claimed by Miller (1945 ; 1946a, b). A somewhat analogous situation was described by Prasanna Varma (1954) when he noticed the occurrence of *Fusarium lateritium* Nees and *F. scirpi* Lamb et Fautr., in our soils producing a typical wilt in tomato comparable in every way to the disease syndrome produced by the well known wilt organism *F. lycopersici* which is known to produce fusaric acid and several other toxins. According to Gäumann and his school of workers (Gäumann, 1957) neither *F. lateritium* nor *F. scirpi* is known to produce fusaric acid. Quite recently, Venkata Ram (1957a) produced evidence to show that under comparable conditions, *in vitro, Fusarium orthoceras* produced 300 mg/l fusaric acid as compared with a paltry 65 mg/l and 35 mg/l of the substance by *F. moniliforme* and *F. vasinfectum* respectively, and the biological identity of the fusaric acid produced was further proved by producing typical vein clearing in cut shoots of susceptible cotton variety K2 (*Gossypium arboreum*). In unpublished work from here, Venkata Ram reports that in Richard's medium adjusted to initial pH 3·0—9·0, a 2-week old culture of *Fusarium orthoceras* growing at the neutral and alkaline pH levels contained approximately 2—3 times more fusaric acid than did cultures in media adjusted to pH levels in the acid range.

It is obvious that during the saprophytic phase in soils these many Fusaria may have to derive considerable amounts of energy materials from plant remains in the form of cellulose and, in fact, Venkata Ram (1956) using 23 species of Fusaria (including *F. moniliforme, F. vasinfectum* and several other potential pathogens) tested their cellulolytic activity on filter paper and bacterial cellulose. Four species did not digest filter paper, but decomposed bacterial cellulose and all the others, except *F. caucasicum,* decomposed both the cellulose substrata. It is significant that *F. moniliforme* and *F. vasinfectum,* inhabitants of Southern Indian soils, over a range of pH 5·0—7·0 had much greater cellulolytic activity than *F. solani* and *F. scirpi,* both known to occur in our soils. The results of this process of utilization of energy substrates in the soil by fungi are many faceted and far reaching in their relationship to plant growth.

There is further undisputed evidence that rhizosphere microfloras of various crop plants, both legumes and non-legumes, monocotyledons and dicotyledons, have another source of exuded energy materials consisting of various sugars, amino acids and vitamins and sloughed off cellulose material from root hairs (Katznelson *et al.,* 1954 ; Rovira, 1956 ; Bhuvaneswari and Subba-Rao, 1957). Facultative fungi of the rhizosphere (many Fusaria have been detected from the rhizosphere of crop plants by us), therefore, largely depend on this steady and apparently unfailing substrate of elaborated food material exuding from roots. Whether this source of energy material is adequate for the building up of the toxins need not be in the realm of speculation, as free fusaric acid has been detected in susceptible cotton plants even on the second day after germination in *F. vasinfectum* infested soils, although from 3—11 days no detectable fusaric acid was seen, again appearing after the 12th day of germination (Subba-Rao, 1957). It may be that the initial formation of detectable quanta of fusaric acid might have been possible by the utilization of energy materials of the rhizosphere by the fungus and for further sustained formation of the toxin the organism might have to find recourse to the *in vivo* substrates vital for synthesis. This is somewhat borne out by the conductivity studies made in this laboratory (Gnanam, 1956) where the conductivity of the sap of the diseased susceptible plant fluctuates very considerably in the first ten days after germination, probably indicating a day to day utilization by way of absorption of the electrolytes and alternately releasing them as evidence on hand suggests *in vivo* chelation of fusaric acid with electrolytes.

VIVOTOXINS

There seems little doubt that antibiotics are formed by fungi in soils and in the rhizosphere and that these are taken up by plants with great facility along with the transpirational stream. Brian (1949) has reviewed this subject in great detail and more recently considerable evidence has been presented on the stability of such antibiotics produced in soils (Jefferys, 1952). In our laboratory, evidence for the production of fusaric acid in garden compost soil by *Fusarium vasinfectum in situ* has been presented (Kalyanasundaram, 1955). This fungus produces fusaric acid equivalent in sterilized soil amended with green leaf and oats up to 2·9 and 7·9 $\mu g/g$. of soil respectively. Other soil amendments like glucose, cellulose, stubbles and farmyard manure were ineffective. Unlike other organisms such as *Aspergillus terreus* and *Penicillium patulum* that are known to produce antibiotics in soils in the presence of glucose alone, *F. vasinfectum* required both organic nitrogen and carbohydrates for the production of what appears to be unmistakably fusaric acid. Recently it has been shown (Venkata Ram, 1957b) that irradiating spores of *F. vasinfectum* with ultraviolet light (2537 Å) with a total energy less than $24{\cdot}73 \times 10^{-7}$ ergs, resulted in mutants, some of which were capable of synthesizing greater quantities of fusaric acid *in vitro* than the parent culture. Some of the mutants that had suffered morphogenetic changes lost their ability to synthesize fusaric acid and Venkata Ram concludes that increase in production of fusaric acid in culture does not seem to be a preferred reaction of ultra-violet induced mutation in *F. vasinfectum*. Kalyanasundaram's observation that detectable quantities of fusaric acid were seen in sterilized soils is a reasonable expectation as this fungus has been shown by Subramanian (1950) to be very susceptible to microbial antagonism and that the growth and persistence of the fungus in soil was limited by the operation of the microbial factor and the inhibition did not come from the respiratory carbon dioxide of the soil microfloras. It may appear less hazardous at present to state that fusaric acid production in soils has a great deal to do with the biological status of the soils and the availability of specific energy substrates.

ENERGY SUBSTRATES

I shall now turn my attention to problems of uptake of metals by plants and the *in vivo* availability of energy sources for the elaboration, distribution, toxigenic responses of tissues and general problems connected with the irreversible type of wilt we come across in fungal root infections. Let me first of all state that heavy metal requirements for normal growth of Fusaria, using stringent bioassay techniques with *Aspergillus niger,* standard M-strain and the M.U.B.L. 1 strain, isolated in this laboratory, as detecting organisms, have been unequivocally demonstrated (Saraswathi-Devi, 1956). The indispensability of Fe and Zn for normal growth (expressed as dry weight yield of the fungus) of 9 species of *Fusarium : F. vasinfectum, F. moniliforme, F. udum, F. scirpi, F. orthoceras, F. oxysporum, F. lini* and *F. poae* has been proved. In fact, we have gone one step further ; fusaric acid, we have shown, is not produced in the absence of zinc or in its presence below 0·08 mg/l, the optimum being 0·24 mg/l. Higher levels of Zn in excess of 0·4 mg/l inhibit the synthesis of this antibiotic despite the fact that the mycelial weight of the fungus continues to remain fairly constant at 0·4 mg/l and higher doses (Kalyanasundaram and Saraswathi-Devi, 1955). Using this argument it appeared that Zn could be one of the causes favouring *F. vasinfectum* wilt of cotton under natural growing conditions in one of our black cotton soils in the Madras State. We have succeeded in demonstrating, using *A. niger* bioassay technique, the following: the Zn content of one of these soils where there is wilt incidence, is at a lower level than that of the other belt of cotton soils where the disease is not prevalent. It appears that the higher Zn content of this second soil may be one of the factors inhibiting production of the toxin, fusaric acid, since it is well established that in both these alkaline soils the same susceptible variety of cotton is grown and the wilt pathogen, *F. vasinfectum* occurs (Saraswathi-Devi, *loc, cit.*)

SOIL CONDITIONS AND HOST PHYSIOLOGY

A word by way of explanation for the choice of Zn for detailed studies seems necessary. This was mainly done because we have had experimental evidence of better seedling emergence in the case of *Cajanus cajan* against soil-borne infection of *Fusarium udum* when the heavy metals B. Mn and Zn were amended at 20, 40 and 80 ppm (Sarojini, 1951). The effectiveness of Zn was even more pronounced than B and Mn in retarding colonization and hastening decomposition of *F. udum* from host stubble buried in such amended soils. Somewhat similar results with cotton wilt Fusaria were obtained using Fe/Mn as soil amendment (Varadarajan, 1953). Fe and Mn added individually and in combination to wilt infested soil reduced the survival of Fusaria, the Fe/Mn combination being superior to the individual elements. The effect of pH in these Fe/Mn amended soils over a wide range indicated that the minimum wilt percentage was at pH 6·0 and the highest rate of mortality at pH 8·3, irrespective of the trace element amendment. Further, typical symptoms of vein-clearing developing on the 12th day after germination in such amended soils disappeared later, and after about 3 weeks these plants were indistinguishable from their healthy counterparts. It is obvious, therefore, that on the acid side the mobilization of the heavy metals was more effective and that both Fe and Mn had a role to play *in vivo* in modifying the disease syndrome. These results we obtained some years ago when less was known about the *in vivo* chelation of wilt toxins but with the present state of our knowledge on the impairment of semi-permeability of the plasma membrane and the fact that wilt toxins can form chelate compounds and act as antimetabolites, we are in a more fortunate position to discuss it at length.

As far as we can visualize, it appears that the wilt fungus seemingly requires *in vivo* metals, pectins and presumably a good nitrogen source as, indeed, the induction of toxaemia appears to depend on the sum total of the substrates available for the development of the mycelium and elaboration of the toxin. For instance, the tetraploid resistant cotton varieties (*Gossypium hirsutum*) Cambodia and Madras Uganda 1 and the diploid susceptible variety K2 (*Gossypium arboreum*) have obvious differences in their ability to synthesize and accumulate non-protein nitrogen (NPN) (Satyanarayana, 1955). During pathogenesis by *F. vasinfectum* the susceptible variety shows a decline in NPN, whereas there is no variation in the protein nitrogen levels (PN). The interesting feature about the resistant varieties is that their organic nitrogen is in the form of proteins and this may be a general pattern associated with resistance and it is possible that the pathogen is unable to utilize the protein substrate in the resistant variety as, indeed, the decline in NPN in the susceptible variety fits in well with the inorganic nitrogen requirement of the fungus *in vitro*. It could be postulated that shoots of the susceptible variety of cotton studied, largely afford the springboard for toxin development *in vivo* by making available larger quantities of nitrogen as NFN. It is needless to emphasize that more genetic varieties have to be studied if we are to understand this mechanism better, and in the cotton it is not only extremely difficult to classify and grade susceptibility or resistance as a gradable syndrome of hypersensitivity to a systemic wilt toxin but would well-nigh be impossible, as it would not be a lasting method with fungi that can produce toxins in varying quantities under *in vivo* conditions of the host. We have circumstantial evidence to show that an equally important *in vivo* substrate for the initiation of toxaemia once the pathogen gains entry into the vessels, is probably pectin, and sizeable quantities have been detected in the roots of susceptible K2 cotton plants, whereas the resistant plants had much less. It has been shown that the root pectin content of the susceptible plants was lowered by Zn amendment to soils, simulating that in the resistant variety. Much work has yet to be done in understanding the *in vivo* production of the twin enzyme systems, pectin methyl esterase (PME) and pectin galacturonase (PG). Our work in this field indicates that evidence of Fe''' in low concentrations in an unbound state, *in vivo*, exerts a potentiating effect on these enzyme systems which in turn produce increased enzymatic degradation of the host substrate (Subramanian, 1956). Zinc and manganese inhibit enzymatic activity, whereas Fe''' increases it but the exact mechanism that triggers this off is obscure. As the concentration of Zn increases, there is a slight increase in PME activity followed by a steep decline at 50 ppm and thereafter, indicating that Zn plays a dual role in that it not only reduces substrate concentration at the focus of infection but also inhibits its degradation by the enzyme.

ENVIRONMENT, TOXAEMIA AND TISSUE RESPIRATION

We have detected high quantities of cystine (Lakshminarayanan, 1955) in resistant cottons and none in the susceptible plant examined and this has been considered to be a limiting factor to wilt. Curiously enough soil amendment with Zn and growing susceptible plants in them results in the greater liberation of cystine even in these plants resulting in the conferment of what appears to be resistance to *F. vasinfectum* in infested soils and the susceptible variety virtually behaves like the resistant one (Subramanian, *loc. cit.*). Equally curious is the fact that production of higher quantities of cystine can be induced in susceptible plants grown at a temperature of 37·5°C. as compared to those grown at 32·5°C. and such plants at the higher temperature showed decreased disease syndrome and a fall in wilt index. This is a case of apparent recovery, as the fusaric acid equivalent is not the same at both temperatures (Kalyanasundaram and Subba-Rao, 1957). It appears that there is a diminution in the available quanta of unbound heavy metal(s) available for toxin potentiation. An alternative explanation also suggests itself, namely, that at the higher temperatures of incubation the saturated and the unsaturated fusaric acid occur in different proportions and the degree of dissociation may have resulted in the utilization of the fusaric acid molecules in respiration thus permitting a recovery or, at any rate, an apparent recovery from typical symptoms. Fusaric acid recovered from such plants grown at 37·5°C showed an increase over that recorded from plants showing characteristic symptoms at 32·5°C., and has been quantitatively assessed by bioassay. It would appear that evidence for the presence of dissociated fusaric acid is well worth looking for, as on theoretical grounds the possibility of dissolution *in vivo* can not be easily ruled out although movement of fusaric acid, essentially in an undissociated condition, in the negatively charged xylem vessels, has come to be regarded as more than a possibility. But it should be conceded that growing of these susceptible cottons at the unusually high temperature of 37·5°C. could alter the host metabolism and create a situation that may be considered far from normal.

The *in vivo* quantitative detection of fusaric acid by a simple chelation of the acid as a copper complex on a chromatogram (Lakshminarayan and Subramanian, 1955) and by the chromatography cum bioassay technique (Kalyanasundaram and Venkata Ram, 1956) has been an important step forward in tackling these vivotoxins and much work using these techniques lies ahead of us.

A recent investigation on *in vivo* changes in fusaric acid distribution in cotton plants infected by *F. vasinfectum* treated to varying photoperiods indicated that fusaric acid was completely catabolized in the series of plants receiving 24 hours darkness, whereas catabolization was partial in plants treated to 24 hours light and such plants showed both fractions of fusaric acid, the saturated and unsaturated molecule responding to detection with R_f values of 0·860 and 0·221 on paper chromatogram. Plants receiving normal photoperiods, 12 hours light, showed the presence only of the saturated molecule with R_f 0·860 (Subba-Rao, 1957). It, therefore, becomes apparent that the plant requires a balanced state of respiration and synthesis for the maintenance *in vivo* of the intact molecule of fusaric acid. Any shift from this appears to bring about degradation of the intact molecule of fusaric acid by a process of decarboxylation (Sanwal, *loc. cit.*).

We have not yet examined the respiratory rates of tissues of susceptible cotton plants (grown at a temperature of 37·5°C.), that show recovery from the disease symptoms despite the fact that they register more fusaric acid *in vivo*. Nevertheless, we have studied tissue respiration in healthy and infected plants grown under ordinary glass house temperatures of less than 30°C., and have established that the net effect of infection of the cotton plant by the pathogen is an increased respiration but the effect of the vivotoxin fusaric acid on tissues is one of inhibition. Respiratory status of susceptible healthy cotton plants in Zn-amended soils showed that Zn depresses tissue respiration and in the inoculated Zn-amended soils the rise in rate of oxygen uptake by the susceptible plants grown in them was counteracted and the rates closely followed those of normal healthy plants (Lakshmanan, 1956). A more comprehensive piece of work on tissue respiration of cotton in the presence of culture filtrates (Lakshmanan and Venkata Ram, 1957) of 21 species of Fusaria grown *in vitro* indicates that filtrates of fourteen species produced high increases in tissue respiration over the control, whereas four species inhibited respiratory rate. Three other species including *Fusarium vasinfectum* caused only slight stimulation in tissue respiration.

WILT AND IONIC DERANGEMENT

I am now almost in the last lap of the difficult task of presenting so many facts before you and would like to wind up by summarising our recent work on ash analysis of cotton seedlings under the influence of *F. vasinfectum* and its toxin.

Spectrochemical examination, by the Lundegardh emission method, of susceptible wilting cotton plant indicated that the key metabolite K shows either a significant loss in mobilization, or with the onset of toxaemia and consequent loss in turgor, the extremely mobile K leaves the tissues and gets exuded (Sadasivan and Kalyanasundaram, 1956). There is evidence to show that Ca and Mg contents increase in such tissues and the greatest increase is that of Mn. The overall position is one of increased accumulation of ions as shown by conductivity measurements (Gnanam, *loc. cit.*). Although resistant varieties of cotton growing in wilt infested soils register a small decrease in K accumulation or uptake compared with the control, there appears to be no comparison with the heavy loss reported in the susceptible plants. It is obvious that *in vivo* tissue damage in the shoot has been very negligible in the resistant plants grown on infested soils as judged by ionic imbalance, and it, therefore, seems safe to conclude that the small loss in K may be due to tissue damage in the rhizosphere region and this has been ascribed to gene controlled mechanisms of the tissues of the resistant cottons (Sadasivan and Saraswathi-Devi, 1957).

Evaluating the bactericidal activity of the antibiotic polymyxin E, Newton (1953) and Few and Schulman (1953) conclude that it is due to its ability to combine with certain groupings on the cell surface, thereby causing disorganization of the membranes, or those structures therein responsible for the maintenance of osmotic equilibrium. Norman (1955) studying the effects of polymyxin B on root growth and root properties of young barley seedlings noticed that inhibition in root development at low concentrations of the antibiotic was reversed in the presence of calcium and in some degree also by other bivalent cations. He suggests that the calcium and polymyxin are retained at the same absorption sites on the roots and that to prevent polymyxin absorption a large excess of calcium is required. It was, however, the only cation, bivalent or univalent, found effective which the barley roots tolerate. As soon as the polymyxin molecule is bound to absorption sites on the roots, root behaviour is changed ; inorganic or organic cell components are released into the medium and the root no longer has capacity for cation uptake. The response of the root to polymyxin exposure depends on direct contact with the antibiotic in solution, and irreversible injury and loss of solutes from the cells occur only in the zone of exposure. If in the rhizosphere population there are organisms which produce substances like polymyxin, roots may undergo localized injury, and energy sources for the rhizosphere organisms may be released and supplement those which may be lost from the roots if they are exposed to wide fluctuations in moisture supply (Katznelson *et al., loc. cit.*).

A somewhat analogous situation is noticed in the case of cotton wilt with *F. vasinfectum*. A detailed study of the calcium lines of various ash samples of susceptible cotton plants at various stages of wilting (Saraswathi-Devi and Sadasivan, 1957) indicates that in addition to the neutral-atom line of Ca at 4226·73Å (which is common for both healthy and diseased plants, although at varying densities), plants that are wilting with typical and clear symptoms and loss in·turgor, as well as those that are apparently healthy but yet have registered a primary loss in K (Sadasivan and Kalyanasundaram, 1956; Sadasivan and Saraswathi-Devi, 1957), show strong ionized Ca lines at wavelengths 3933·7 and 3968·47 Å. The resistant Cambodia plants also show much more of ionized Ca than the susceptible variety but there is no apparent increase in the plants grown in infested soil over its control. However, the ionized Ca lines are pronounced in the plant that has apparently no symptoms but where *in vivo* changes due to fusaric acid damage have already become apparent as judged by significant loss of K. It is probably premature to decide whether Ca^{++} is the only bivalent cation that is released in this fashion. It appears that Ca, with the present data, has to be considered as the one element ionized rapidly *in vivo* as soon as the fusaric acid molecule dissociates and possibly utilized in respiratory processes. It is needless to add that the disappearence of K in large quantities seems to be an established fact in our series of experiments presumably as part of exudates hastened by loss of turgor as, indeed, the extraordinary mobility of K would easily permit of this movement. It is obvious that, both in the fully flaccid plant, as well as in the apparently healthy one, on the verge of wiltihg, the ionized Ca lines are much stronger than in the healthy plant. It is, therefore, a strong case for consideration whether in both cases the cells show a poisoning effect as otherwise, release of ionic material does not seem to normally take place from normal turgid cell of the susceptible plants.

EPILOGUE

To the casual observer of problems of plant pathology it may appear somewhat bewildering that such masses of data are available and have been collected by so many in different parts of the world in what may be called a relatively obscure disease like pathological plant wilts. To the specialist, it all means a great deal of stimulation for further work as in the understanding of fundamental life processes of host and parasite lies the key to a proper realization of functional mechanisms of micro-organisms and the response of tissues to their products of metabolism. It is for this very reason that the study of moulds, after the most significant biological discovery of the age—the antibiotics, has not only become fashionable but has led to a good deal of co-operative effort between scientists belonging to many disciplines of science. As far as I can see, I am inclined to lay emphasis on a more intensive study of the energy substrates obtainable from many host plants in the region of the rhizosphere and *in vivo* on which depend the growth and development of pathogenic fungi and other micro-organisms. An equally intensive survey of the fate of vivotoxins and the changes they bring about in primary cell functions should be launched, for, after all, the pathways to human welfare and progress lie as much in the study of behaviour patterns in microbes and lowly forms of life as in the study of the most complicated and most respected specimen of biological perfection—Man.

In all humility, I quote the Kathopanishad:

> "अणोरणीयान् महतो महीयानात्मास्य जन्तोर्निहितो गुहायाम् ।"
>
> "The Atman, subtler than the subtle, greater than the great, is seated in the heart of each living cell."

I have endeavoured to make my subject for this address as interesting and scientific as possible but if I have failed to adequately cover certain aspects of the problem set before me, you have my apologies. The main aim of these stock-taking addresses annually by someone specialising in a particular line is perhaps to enthuse younger workers in the Country to concentrate on these fundamental problems and if I have fulfilled that task, I shall resume my seat mightily pleased.

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SECTION OF ZOOLOGY AND ENTOMOLOGY

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PRESIDENTIAL ADDRESS

SOME ASPECTS OF REPRODUCTION IN INDIAN FARM ANIMALS

May I begin by expressing my deep sense of appreciation of the honour that the members of the Sectional Committee have done me in electing me to the Presidential Chair on this occasion. I must admit that the selection of a subject for this address posed some difficulties for me, as in these days of intense specialization it is not an easy task to select a subject which would appeal to all the workers serving in varied branches of Zoology. The zoologists of today have left the beaten tracks of their predecessors who had kept themselves confined mostly to morphology and systematics, and are breaking new grounds, like their colleagues in other branches of scientific discipline, and are contributing knowledge which can be applied directly to human welfare.

There can be no two opinions on the fact that the greatest problem of India today is that of food and population. Food production in India is intimately connected with animal husbandry. Agricultural operations in the country are even now almost exclusively dependent on cattle, as the bullock is the mainstay for motive power not only for tilling the soil and other farm operations but also for transport of farm produce from rural to urban areas. Besides, farm-yard manure forms the main bulk of fertilizer for enriching the soil. Contribution of cattle to national health is also enormous, for milk and milk products provide the only source of animal protein for a vast proportion of our population. Unfortunately, we are getting only a small fraction of the potential benefit from our farm animals as in India the animal industry has so far remained the Cinderella in the fields of science and development. Any knowledge which can be harnessed for improving our animal production must, therefore, be of immense value for human welfare in the country. Economic animal production is, therefore, of paramount importance and it deserves far more attention than it has received so far. In the words of Hammond, one of the world's leading scientists in the field of animal production, 'the rate and efficiency of the process of reproduction is the first basis of economic production'. I have, therefore, chosen to address you on 'some aspects of reproduction in Indian farm animals.' Another reason which prompted me to select this topic was the fact that I, with my colleagues at the Indian Veterinary Research Institute (IVRI), Izatnagar, have been working in this field for a number of years. Research connected with the reproduction in farm animals in India is of recent origin and the work so far carried out is by no means complete in any aspect. It is, therefore, difficult to present an integrated picture. I shall, however, endeavour to review the work so far done and suggest, wherever possible, the direction in which investigations could be taken up in future.

REPRODUCTION IN THE MALE

ROLE OF PRECOITAL SEX-PLAY, COITUS AND SEMINAL PLASMA IN REPRODUCTION

For quite a while, it was generally believed that precoital sex-play, the act of coitus and the seminal plasma had no vital role to play in reproduction. This impression gained ground because of the development of artificial insemination (AI) in which it was established that a minute quantity of semen deposited in the female tract by instruments was apparently as effective in fertilization of the ovum as natural mating or deposition of a large volume of semen. It was also noted that the seminal plasma was possibly not necessary for fertilization, as good fertility results could be obtained by the use of washed or epididymal spermatozoa (Walton 1930, Young 1931, Lardy and Ghosh 1952).

In the light of the recent developments, it has become necessary to somewhat modify the older concepts. It is now being realized that precoital play though not essential in reproduction, may not be completely redundant as observations by a large number of workers and also objective experiments, have established that sexual excitement prior to service is one of the factors which appreciably affects the semen production and its quality (Anderson 1945). Herman and Swanson (1941) observed that when two collections were made in quick succession from dairy bulls, the second ejaculate had a larger volume and a higher concentration of spermatozoa. Mercier and Salisbury (1946) also noted that the second ejaculate contained a larger number of actively motile spermatozoa as compared to the first ejaculate. In our work with buffaloes (*Bubalus bubalis L.*) it was observed that the quality of the second ejaculate was generally better than the first and the former contained less number of abnormal or dead spermatozoa (Prabhu and Bhattacharya 1951). The improvement in the quality of the second ejaculate may perhaps be ascribed to the additional excitement obtained by the bull due to its longer presence before the female. It was also noticed that changes in the objects of excitement prior to collection influence the semen attributes in the buffalo bull (Prabhu and Bhattacharya 1954, Prabhu 1956). Similar observations in the bull have been made abroad (Milovanov 1934, Rowson 1946). Knowledge in this field is still very meagre and even less is known on the effect of precoital excitement on the female reproductive system. The importance of studies on the effect of animal behaviour on reproduction is being increasingly felt all over the world. A modest beginning in this direction has been made at Izatnagar.

In his studies on rabbits, Heape (1890) noted that ovulation followed coitus and he believed that at least in rabbits, ovulation was brought about by the stimulation of the ovary as a result of an induced nervous reflex. Recent work of Markee and coworkers (1946) has given support to this view and a new concept of neurohumoral mechanism of ovulation has grown. It appears that the natural neurogenic stimulus of coitus with its cholinergic and adrenergic components brings about ovulation through humoral means. Probably the cholinergic component of the stimulus induces the secretion of the adrenergic mediator which, in its turn, stimulates the pituitary cells to release the luteinizing hormone. Indications that the neurohumoral mechanism of ovulation is also operative in spontaneously ovulating animals like cattle were first obtained by Marion and coworkers (1950). They found a significant difference in the ovulation time following oestrus in heifers that were given sterile copulation and those that were left unmated. Subsequent work using nerve blocking agents like atropine gave added support to the view that neurohumoral factor is involved in the ovulation of dairy cattle (Hansel and Trimberger 1951). Investigations on sheep and poultry have also indicated neurohumoral mechanism in ovulation (Nalbandov *et al* 1956, Van Tienhoven *et al* 1954). These findings do indicate that though coitus may not be quite essential in reproduction yet it affects the functioning of the reproductive system in some way, the exact nature of which is not yet completely understood.

After it was established that epididymal and washed spermatozoa could effectively fertilize ova, doubts naturally arose whether seminal plasma, besides acting as a vehicle for the transport of spermatozoa, had any other essential role to fulfil in the process of reproduction. Biochemical analysis of the seminal fluid of farm animals revealed that it contains a large number of chemical substances many of which were biologically potent. It contains for example, spermine, choline, ergothioneine, creatine and creatinine, adrenaline, fructose, glucose, citric acid, sudanophil material and inositol. Various enzymes such as fibrinolysin, aminopeptidase, pepsinogen, acid phosphatase, alkaline phosphatase, pyrophosphatase, ATP-splitting enzyme etc., are also present in semen. It would really be surprising if all these large array of chemical substances present in it have nothing to do with the reproductive processes. Mann (1948) has proved that in the absence of oxygen, spermatozoa rely on fructose in the seminal plasma as the chief source of energy. It must, of course, be admitted that our knowledge regarding the role of seminal plasma in reproduction is very fragmentary and incomplete.

With a view to determining whether or not the seminal plasma influences the reproductive function of the female, a series of investigations have been conducted at Izatnagar using rabbits as experimental animals. The semen of the rabbit on ejaculation separates out in two portions—a liquid portion and a gelatinous mass. It was formerly believed that the gel mass merely filled the lumen of the vagina after ejaculation as a mechanical plug and prevented the semen from running out of the vagina (Allen *et al* 1939). It was not known to have any other function. It was, however, known that the quantity of gel mass per ejaculate in rabbit semen increased with hormone administration (Parsons 1950). Our investigations showed that the gel mass of rabbit semen kept a number of spermatozoa arrested in a temporary inactive state. At the vaginal temperature of the rabbit, the mass underwent slow liquefaction and released the arrested spermatozoa (Mukherjee *et al* 1951, 1953a). It is thus apparent that the vaginal plug formed by the gel mass does not merely act as a mechanical barrier to the out-flow of semen but it also helps in holding a large number of spermatozoa in a temporary inactive state and in retaining their ability to fertilize ova over a longer period. It is possible that in rabbits which are multiparous animals, the retention of spermatozoa in an inactive state in the gel mass for some length of time and their subsequent gradual liberation is necessary for fertilization of a number of ova which may not be shed all at one time. It was also observed that the gel mass contained oestrogenic hormone (Mukherjee *et al* 1951) and that the administration of pregnant mare serum gonadotrophin (PMS) in male rabbits not only increased the quantity of the gel mass in the ejaculate but also the oestrogenic content of the gel mass (Mukherjee and Bhattacharya 1953). Intravaginal administration of the gel mass caused hyperaemia and hypertrophy of the uterus in both mature ovariectomized and immature intact rabbits and in the latter the ovarian follicles also became enlarged (Mukherjee *et al* 1953b). The gel mass administration also increased the pituitary weight and the percentage of the acidophils. The adrenal weight also increased and the cortex showed histological evidence of enhanced activity (Mukherjee and Bhattacharya 1954a). Hyperactivity of the thyroid was observed and possibly as a consequence there was a marked increase in the rate of respiration (Mukherjee and Bhattacharya 1954b).

Prior to these investigations on rabbits, no experimental evidence was obtainable on the absorption of substances in seminal plasma through the vaginal wall though such suggestions were advanced by others on the basis of clinical observations. Green-Armytage (1943) made clinical observations on 40 married women divided into two equal groups. One group practiced contraceptive measures from the commencement of married life while in the other the marital union was free from such measures. The gynaecological examination made in the beginning of married life revealed small uterii in majority of women in both the groups. After four and a half to seven months of married life, the uterus was found to have grown to normal size in nine out of fifteen women in the latter group, whereas in the former only five women showed normal sized uterus even after a period of two years. This difference was attributed to the absorption through the vaginal wall of hormonal substances from the semen. MunroKerr (1946) stated that 'Recent investigations suggest that in many women full maturity of the uterus and genitalia depends upon the absorption by the vaginal mucous membrane of a growth hormone in the healthy human semen. Therefore, anything or any method which prevents, retards or alters the normal degree of physiological absorption of human semen from the vagina carried with it during the early months and years of marriage the risk of future sterility from failure of uterine development and/or endocrinal asynchronisation.'

Using biological methods, Rusfeldt (1948) demonstrated the presence of oestrogenic hormone in human semen but Natoli (1950) using the same method failed to demonstrate its presence. McCullagh and Shaffenberg (1951) also detected the presence of oestrogenic substances in human and bull semen. The observation of Green-Armytage and MunroKerr can be explained on the basis of oestrogen absorption from the semen. The presence of oestrogens in semen can also be surmised from the work of Durrell (1947) who observed that injections of semen from bulls into the cervix induced oestrus in 6 out of 12 anoestrous cows. Kozenko and Smirnov (1952) induced oestrus not only in anoestrous cows but also in anoestrous sheep and pigs by the uterine administration of diluted or undiluted fresh semen. Johari (1956) while working in Sweden, detected the presence of oestrogenic substances in the boar semen. The presence of androgens has also been detected in human, bull and stallion semen (Mann 1954). In a very recent experiment, Mann and coworkers (1956) used three components of semen, viz: fructose, ergothioneine and citric acid as 'chemical indicators' and noticed that these seminal components rapidly decreased in quantity on introduction into the genital tract of gilts and mares. To what extent this decrease is due to 'absorption' or 'digestion' remains to be explained, but whatever may be the mechanism for the decrease, there seems to be no doubt that substances present in seminal plasma enter the female system either as such or in modified form.

It is quite possible that besides oestrogens and androgens, seminal plasma contains other hormones. It is likely that the seminal hormones influence the endocrine glands, especially the adrenals and the thyroid, as observed in the rabbit, and increase the blood supply to the uterus. The increased blood supply may provide a more favourable uterine environment for the nourishment of the fertilized ova prior to nidation. From what is known so far, there seems to be little doubt that the seminal plasma plays some role in the process of reproduction which may be quite important. Much more research is, however, required to unravel a fuller picture.

REPRODUCTION BY ARTIFICIAL INSEMINATION

Artificial insemination as a means of reproduction in livestock breeding is not a modern invention. It is reported that as early as in 1322, an Arab chieftain bred a prized mare with semen stealthily collected from a rival chieftain's stallion. On scientific lines, AI was first practiced by Spallanzani (1780) in bitches but its use in practical husbandry came into being after the pioneering work of Ivanoff in Russia towards the end of the nineteenth century. The chief limiting factor in the improvement of livestock in this country is the poor genetic constitution of the large portion of our farm animals. Betterment of the present degenerate stock would, therefore, demand primarily improvement in the genetical make-up of their economic characters. To bring about a rapid improvement in the genetic constitution, the greatest possible use of superior sires has to be made. There is, however, an appalling shortage of good quality sires in the country. In cattle for example, it has been estimated that we have only one bull of the desirable kind in place of a thousand required. In a situation so circumscribed, AI can play a great role in hastening the improvement of breeds as thousands of cows can be served in a year by this method by one bull instead of 50-60 possible by natural mating. One or two isolated attempts at AI had been made in India since 1939 (Kumaran 1951) but its systematic investigation was started in 1942 at the IVRI. Collaterally with laboratory research at Izatnagar, AI service was extended to the neighbouring villages. Early experience gained suggested that so far as the technique was concerned there was no difficulty in utilizing the method in animal husbandry practices of the country. It was, however, thought desirable to extend the work further to study organizational problems and gather necessary information for further planning. Four regional centres were established between 1945 and 1947. In spite of many difficulties encountered, encouraging results were obtained at these centres and the work done amply demonstrated the practicability of large-scale utilization of AI in India (Bhattacharya 1946, 1949, Bhattacharya and Prabhu 1952, 1954, 1955). Artificial insemination has now found an important place in the animal husbandry activities of the country. The master plan of cattle regeneration—the Key Village Scheme—has recognized AI as essential to the success of cattle improvement. During the First Five Year Plan, 150 AI centres were opened in 600 Key Villages and a total of about 1,00,000 cows were inseminated. It is envisaged that 245 more centres will be opened in 1448 Key Villages during the Second Five Year Plan. Artificial insemination has also found a place in the National Extension Service Plan.

The early work of AI in India indicated the need of seminological studies of Indian farm animals. It was also considered desirable to undertake research on evolution of more efficient dilutors and on the factors that affect the semen quality.

SEMEN CHARACTERISTICS.

In spite of the fillip that AI has received in India, it is surprising that so little work has so far been undertaken to determine the norms of the semen characteristics of various breeds of different species of Indian livestock. Kumaran (1951) studied some semen characteristics of Sahiwal and Amritmahal bulls at Delhi and Mysore respectively and Ayyar (1944) of Ongole bulls at Madras. Shukla and Bhattacharya (1949) made investigations at Izatnagar on the semen characteristics of Hariana, Sahiwal, Kumauni hill and Murrah buffalo bulls and also of sheep and goats. Sharma and others (1957) from Hissar have reported on some of the semen characteristics of Beetal goats. From the limited studies that have so far been made, it appears that the semen characteristics of Indian farm animals do not markedly vary from those reported for European livestock. Bhattacharya and Prabhu (1954) made an analysis of records of semen characteristics from three regional AI centres and found that, on an average, the volume of ejaculate from European bulls tended to be higher than from Indian bulls. They also found that the volume of ejaculate from buffalo bulls was significantly lower than that of bulls. In a large number of AI centres in India, semen studies are now being made as a routine measure. It would be interesting to have all the available data collected, collated and analysed.

Besides investigations on the 'normal' values of certain physical characteristics of semen of Indian farm animals, some cytomorphological studies have been made at Izatnagar on the spermatogenesis of the Indian buffalo (Bhatnagar 1952). It was observed that while the mitochondria are found in a scattered state in spermatogonia and spermatids, they form a horseshoe like structure in the spermatocytes. In the fully developed spermatozoon, the mitochondria surround the axial filament to form the middle piece. The Golgi bodies appear as a clumped mass at one pole of the nucleus in spermatogonia and spermatocytes. In the spermatid, the Golgi material divides into two—one travels down the cell while the other divides into granules forming a bead in a fully developed speramatozoon. Knudsen (1954) in Sweden, observed a few types of chromosomal aberrations in bulls with congenital disturbances in spermatogenesis which were similar to anomalies causing sterility in plants. He also found that bulls with acquired disturbances, on the other hand, formed a well defined group from the point of view of the changes in the spermatogonial epithelium. The physical characteristics of semen from these bulls, however, appeared normal. Knudsen's observations have opened up a very important field of investigation which will help in detecting certain forms of sub-fertility in the male and such studies will be useful in the investigations in bovine infertility now being taken up in India. Mukherjee and Bhattacharya (1949) during the course of investigation on the development of spermatozoa at different parts of the male reproductive tract studied the changes in the kinoplasmic beads. These studies have been carried out in buffaloes, rams and goats. It was observed that the beads are not homogeneous structures and the staining characteristics suggested that they contain a large number of Golgi bodies held together by protoplasmic mass. As the beads travel from the proximal to the distal end of the middle piece of the spermatozoa, the Golgi bodies are reduced in number resulting in the diminution of size of the beads. The reduction in number of the Golgi bodies might be due to certain changes which lead to the formation of sudanophil fat. Bhatnagar (1952) observed that the Golgi elements of the beads in buffaloes are remnants of the Golgi bodies of the secondary spermatocytes. The function of the beads is not clear but it seems that they are connected in some way with the maturation process of the spermatozoa. The fact that the beads are not present at the time of ejaculation suggests that their functions, whatever they may be, are confined to the period during which the spermatozoa are residing within the male tract.

In the course of observations on sperm morphology, the acrosomal cap was noticed to cover the anterior region of the head of spermatozoa in all the three species. The structure appeared phobic to ironhaematoxylin and it was very prominent on spermatozoa obtained from the epididymis. It is a bladder-like structure without protoplasmic matter in it. The shape may vary from a prominent regular cap to that of an irregular cap just protruding on the anterior end of the head. In the bull, Rao and Hart (1948) also observed this irregularity in the shape of the acrosome. The irregularity in shape of the acrosome as pointed out by Mukherjee and Bhattacharya (1949) may be due to the effect of handling of spermatozoa prior to fixation. On account of the extremely delicate structure of the acrosome it is liable to become irregular in shape very easily. Bhatnagar (1952) in his studies on buffaloes noticed that the acrosomal cap of the spermatozoon is formed by the membrane of the archoplasmic vacuole and its fluid. Bishop and Austin (1957) have reported that the acrosome is a double structure consisting of inner and outer caps. Cytomorphological studies in living spermatozoa have greatly been facilitated by recent developments in fluorescence microscopy. According to these authors the acrosome seems to carry the hyaluronidase enzyme which possibly enables individual spermatozoon to penetrate through the follicle cells. Hancock (1953) reported a hereditary acrosomal deformity in the bull spermatozoa which was associated with complete sterility.

With the introduction of better techniques, like phase contrast, interference, fluorescence and electron microscopy, our knowledge on sperm morphology has improved a great deal. But I have to admit with regret that many of these refined equipments have not yet been used in India for biological investigations in the field of animal husbandry. It is admitted that the paucity of personnel adequately trained in these techniques and the high cost of some of the equipments such as electron microscope, preclude the possibility of many laboratories undertaking intricate studies on cytomorphology, but there should be no difficulty in taking collaborative work with those institutions which are already equipped with such implements and personnel.

The characteristic peculiarity of active movement of the spermatozoa led many to believe that the travel of spermatozoa up the Fallopian tubes for fertilization of the ovum resulted from the motility of spermatozoa themselves. It is now known that the transport of spermatozoa is primarily the consequence of rhythmic muscular contractions, of the wall of the uterus and the tubes and of currents produced by the movement of cilia lining the Fallopian tubes. Even carbon particles or dead spermatozoa are transported almost as rapidly up the Fallopian tubes as actively motile spermatozoa. VanDemark and Hays (1954) investigated the speed with which the spermatozoa travelled up the Fallopian tubes to the ovarian end in cows and found that spermatozoa reached there in less than 2 to 4 minutes following the deposition of semen in the cervix. Rao (1954) at Izatnagar, found that the speed of sperm transport in buffaloes was about the same as in cows and that spermatozoa reached the anterior third of Fallopian tubes in 3 minutes 10 seconds in natural service and 3 minutes 20 seconds in AI.

Besides the observations on the physical characteristics of spermatozoa, some investigations on biochemistry of semen have also been conducted in our laboratory. From their work Roy and coworkers (1950a) have found that the concentration of the non-fructose residue in the buffalo and rooster semen was higher than in the goat and the ram ejaculate as well as in bull semen as reported by Mann (1946). Ascorbic acid content of the semen of Kumauni hill bulls was found to be about 4 times higher than the corresponding concentration in buffalo semen. In Kumauni hill bulls, a significant positive correlation was found to exist between the ascorbic acid content and seminal fructose but this relationship was non-existent in the case of buffalo semen (Pal *et al* 1956). The identity of the chemical nature of the non-fructose residue is not yet known, nor what role, if any, this residue plays in sperm physiology.

Mann (1945) has established that fructose is the principal reducing sugar of seminal plasma in contrast to glucose which is the main reducing carbohydrate in other biological fluids. He has also stated that the amount of fructose consumed by spermatozoa (fructolysis) is a measure of spermatozoal activity. Fructose contents of bull, buffalo, ram and goat semen have been estimated at Izatnagar (Roy *et al* 1950a, Luktuke 1954, Pal *et al* 1956). A wide range of variation was observed in the sugar content of semen within breed and between ejaculates collected from the same animal. The average fructose content of bull, buffalo, ram and goat semen in mg/100 ml was found to be 800, 515, 529 and 465 respectively. Mann (1954) has reported an average content of 540 for the bull and 247 for the ram. Sugar utilization of bovine spermatozoa over a period of 3 hours at 37°C was also investigated by Luktuke (1954) and it was found to vary between 35·5 and 54·2% of the initial content in the ejaculate. Roy and others (1950b) working with semen of buffaloes, rams and goats, noticed that the relation of the volume of ejaculate to the concentration of fructose and of sperm concentration per unit volume to fructolysis are linear. These workers also made a test for comparative reliability of fructolysis, initial fructose content and methylene-blue reduction time (MBRT) for ascertaining the sperm concentration in buffalo semen and found that fructolysis and the initial fructose content are superior indices than the MBRT. Pal (1957) from his analysis of buffalo semen found that the concentration of fructose, calcium, inorganic phosphorus and non-protein nitrogen was higher and that of citric acid, organic phosphorus and total nitrogen lower in this species as compared to corresponding figures in bull semen as reported by Mann (1954).

Very recently Roy (1957) working at Mathura, has detected the presence of an egg-yolk-coagulating enzyme in the goat semen. This enzyme, produced in the Cowper's glands, is activated by the addition of calcium in the medium and is depressed by the addition of citrate or oxalate. Spermatozoa, freed from this enzyme, show great improvement in viability. Production of this enzyme appears to be dependent on testosterone.

DILUTION AND PRESERVATION OF SEMEN

The success of AI in livestock breeding is largely due to the development of efficacious dilutors and methods of preservation. Two extenders that are most widely used for dilution and preservation of semen are the

Egg Yolk Phosphate (EYP) and the Egg Yolk Citrate (EYC) developed by Phillips and Lardy (1940) and Salisbury and collaborators (1941) respectively. In connection with routine insemination, it was apparent in several AI centres in India that buffalo semen could not be preserved as efficiently in the EYP and EYC dilutors as the bull semen. Srivastava and others (1953) reported that the life of buffalo spermatozoa *in vitro* could be appreciably extended through the use of only the active principle of the egg-yolk reported by Mayer and Lasley (1945) in the dilutor instead of the whole yolk. Later, Srivastava and Prabhu (1956) tested the relative efficacy of a dilutor formulated by Kampschmidt and others (1951) with addition of sulphamezathine (G), egg-yolk-active-principle dilutor, EYP, EYC, autoclaved milk and 'Spermasol' (a proprietory product) for use with buffalo semen. They found that the *in vitro* keeping quality of 'G' dilutor was superior to others tested. The actual fertility results with 'G' dilutor were as good as with EYP or EYC.

Recently Roy and Bishop (1954) reported from Cambridge that a diluent composed of equal volumes of pure glycine solution (up to levels of at least 4%) and egg-yolk was much more effective than the EYP or EYC dilutors in slowing down the rate of decline of motility in stored bull semen. The addition of small amount of fructose and arginine tended further to increase sperm survival. In one instance, a semen sample diluted with glycine-fructose-egg-yolk medium appeared good enough for insemination after 50 days' storage and contained some progressively motile spermatozoa even after 65 days. Roy and coworkers (1955, 1956) at Mathura found that egg-yolk diluent with glycine preserved buffalo and ram semen appreciably longer than EYC. Conception rate in buffaloes was also slightly higher with the use of glycine-yolk diluent. Though the motility of spermatozoa can be preserved in this dilutor for a much longer period, the fertility results in cows have not generally been shown to be better than with other dilutors. For boar semen, however, this dilutor has proved to be the best so far.

A group of workers abroad have of late been advocating the use of milk as semen dilutor and several AI organizations particularly in the U.S.A., have already adopted it on considerations of economy. Flipse and Almquist (1956) found that addition of glycine in skimmilk improved the livability of spermatozoa and that skimmilk-glycine dilutor was as good as egg-yolk-glycine dilutor. In Madras, Ayyar (1952) tried boiled milk with citrate buffer as a dilutor for bull and buffalo semen and found that semen could be preserved in this medium as effectively as in egg-yolk dilutor.

An accidental discovery in the U.K., by Polge and collaborators (1949) showed that spermatozoa of the fowl mixed with a medium containing glycerol could be preserved by freezing. This has opened out revolutionary possibilities in the practices of artificial insemination. The initial success with fowl semen opened ways for similar preservation of bull semen. The method of deep-freeze preservation (-79°C) of bull semen has reached such a stage of perfection that normal calves have been obtained from semen stored for more than three years. It has been reported by Madden (1956) that frozen semen used within two months of freezing yielded 60·5% conception rate as against 62·2% from the use of 27-34 hours old non-frozen semen. It now appears that spermatozoa can be kept preserved for years; may be indefinitely. As a consequence of this, practically all wastage of semen may be eliminated and from the very best bulls in the world, insemination may be arranged in any other part of the globe; a few hundred bulls would suffice for insemination of all the cows in a country; and it would also be possible to obtain progeny from an outstanding sire, long dead and gone. Exploratory work on deep-freezing of buffalo semen has been undertaken at Izatnagar.

The most recent development in semen preservation is the success obtained by VanDemark and Sharma (1957) in the U.S.A. in keeping bull spermatozoa alive upto six days at room temperature (around 22°C) by incorporating carbon dioxide into a suitable diluent and hermetically sealing the diluted semen in ampoules. This progress in semen preservation is of great importance for countries like India where in many places refrigeration facilities are not available.

FACTORS AFFECTING THE SEMEN QUALITY

Innumerable factors influence the quality of semen in farm animals but because of limitations of time, I would touch only on a few aspects which are of importance in animal breeding. With the advent of AI, an answer to the questions as to when the bull should be allowed to serve and what is the optimum frequency of collection from the bull have become very important. Considerable amount of investigations have been carried out in foreign countries by studying breeding records or by controlled experiments to get answers to these questions. Opinions are not yet agreed and the questions are still open. It is, however, now recognized that there are great individual variations in bulls with respect to the frequency of collection which they may be able to withstand in puberty and in adulthood without detrimental effect. Heredity, nutrition, climate or management, all these may individually or collectively cause such variations. It is unfortunate that practically no information is available for Indian animals on these aspects. Recently a controlled experiment has been undertaken at Izatnagar to study the effect of the frequency of collections on the semen quality of mature bulls. From the results obtained so far, it appears that twice-a-week collection taking two ejaculates on each collection day, adversely affects the semen quality in Kumauni hill bulls if continued longer than one and half months as evidenced by decline in volume and total sperm production (Gajjan Singh 1955). Further investigation is in progress.

That a reasonable amount of exercise is necessary to keep the breeding sire in good trim is agreed by all animal breeders, but informations are lacking on the extent of exercise that is required to maintain the bulls in best breeding condition. In a controlled experiment at Izatnagar, Prabhu and Guha (1952) studied the effect of one hour walking exercise just prior to collection, two levels of exercise (one hour and two hour walking) and lack of exercise (one month's rest) on semen quality and 'reaction time' (the time interval between the approach of the bull to the cow and actual service) in bulls. The effect of exercise just prior to collection was exhibited only by a decline in the volume of the ejaculate. Bulls which received no exercise for a long period showed degeneration of the semen quality by way of significant change in the pH and increase in the percentage of abnormal spermatozoa. No difference was noticed in the semen quality of bulls getting one-hour exercise or two-hour exercise. There was no significant difference in 'reaction time' with any of the treatments.

Knowledge on the optimum requirements of the various nutrients for breeding bulls is still extremely inadequate though the requirements for milk production or for growth have been worked out fairly completely. There is relatively more information available regarding the effect of different planes of nutrition on the physiology of reproduction in the female.

A series of experiments were conducted in the U.S.A., for investigating the relationship of different levels of feed intake in young bulls to their rate of sexual development and semen production and it was observed that total digestible nutrient intake of 60—75% of that recommended by Morrison definitely delayed the onset of semen production in young bulls. Nutrient intakes of 120—140% of the recommended amount brought young bulls in semen production earlier than those having normal intakes. Prabhu and coworkers (1953) studied the effect of replacement of crude proteins by blood meal in the ration of Kumauni hill bulls. They found that replacement to the extent of 30% did not cause any significant difference in semen characteristics. Larsen and Sorensen (1944) in Denmark observed that when 70% of the protein fed to the bulls was of animal origin, there was marked increase in sperm density. Flipse and collaborators (1956) replaced most of the vegetable protein in the ration of the bull by fluid skimmilk or dried skimmilk for studying their effect on semen production. An apparent advantage was observed in sperm concentration by using animal protein in the ration.

Spermatogenic activity goes on continuously in the male after the attainment of puberty but it has been found by various workers in different parts of the world that the quality and quantity of semen of farm animals vary during different seasons of the year. Mukherjee and Bhattacharya (1952) studied the seasonal variations in the 'reaction time' and certain semen characteristics of Kumauni hills bulls. There was significant seasonal variation in initial motility, sperm concentration and percentage of spermatozoa, though the 'reaction time' remained unchanged. On the whole, the quality of semen was found to be better in spring (February to April) and poorer in autumn (August to October). Spring was marked with moderate air temperature, lowest relative humidity and scantiest rainfall. Autumn recorded high temperature associated with high humidity and rainfall. Similar investigations were also made in rams and goats (Shukla and Bhattacharya 1952a,b). As in the case of bulls, significant seasonal changes were noticed in semen characteristics in these species as well. The pH of semen, however, did not show seasonal variation in the goat. Rams were similar to bulls in 'reaction time' and showed no variation. Goats differed from bulls and rams in showing significantly lower 'reaction time' in summer (May to July) than in other seasons. Roy and others (1950b) in their biochemical studies on ram semen noted higher MBRT and lower fructolysis rate in autumn indicating deterioration of semen quality during that part of the year.

Kushwaha and collaborators (1955) studied the seasonal effect on 'reaction time' and a number of semen characteristics in Murrah buffaloes and noticed that the average 'reaction time' was significantly higher in spring than in autumn and winter. In this species, the total number of spermatozoa as well as initial motility were highest in summer but the percentage of abnormal spermatozoa was lowest in spring. Malkani (1954) in her investigations on Surti buffaloes at Anand, noticed marked seasonal variations in the semen quality. For most of the semen characteristics spring was found to be the best; next best was winter and autumn was the worst.

It is established that alterations in the thermal environment cause changes in the morphology of the thyroid and the adrenals (Bernstein 1941). Prolonged exposure to cold causes hyperplasia of the thyroid and diminution of follicular fluid (Starr and Roskelly 1940). This action of cold on the thyroid appears to be mediated through the anterior pituitary as hypophysectomy or sectioning of the hypophyseal stalk prevents the manifestation of the thyroid response (Wolf and Greep 1937, Uotila 1939a, b). Berliner and Warbritton (1937) observed that the higher air temperature in summer creates a hypothyroid state in rams as a result of which their testicular activity decreases. Opinion is now veering on to the view that the climatic effect on the reproductive organs is mediated mainly through the endocrine system. The seasonal histological changes in some endocrine glands in buffaloes, rams and goats have been studied at Izatnagar (Bhatnagar *et al* 1955 ; Mukherjee *et al* 1957). Thyroid and testes were studied in the buffalo ; the thyroid, testes and adrenals in rams and goats. From these investigations, it appeared that the thyroid and testicular activities were controlled by both atmospheric temperature and humidity and that the thyroid activity was correlated with the activity of the testes. The histological changes in the adrenal cortex as observed in rams and goats followed the trend of the thyroid and testes.

Various attempts have been made to cure 'summer sterility' by administration of thyroactive materials (Berliner and Warbritton 1937, Bogart and Mayer 1946, Warwick *et al* 1948, Eaton *et al* 1948). Workers at Izatnagar tested the efficacy of a thyroactive substance—'Protamone'—(Mukherjee *et al* 1953c, Roy *et al* 1953) and l-thyroxine (Goswami 1957) for this purpose in goats and buffaloes respectively. The results were not encouraging. In goats, the administration of the drug increased the sperm concentration per unit volume but decreased the total volume of semen. The treatment also caused physiological upset in goats as evidenced by changes in the pulse rate, rate of respiration, body temperature and body weight (Mukherjee *et al* 1953d). It was quite obvious that the dosage given (1 gm/animal/day) was not suitable under Indian conditions. More recent work with lower dosage also have not shown encouraging results in improving the semen quality but it was observed that a dosage of 0·5 gm/animal/day could be tolerated by the goat without harmful effects. Luktuke and Bhattacharya (1952) and Goswami (1957) made attempts to improve the quality of semen by directly activating the testes with the administration of PMS in rams and buffaloes respectively. Some encouraging results were obtained by such hormone treatments.

Knowledge regarding the seasonal variations in the efficiency of reproduction and production in animals have made the investigators in animal science increasingly conscious of the importance of studies on the climatic influence on the various organs of the body, as reproduction and production are only the reflections of the efficiency of functioning of the different physiological systems. As a consequence, a great deal of active research has been carried out in recent years in this field leading to the establishment of a specialized branch of animal science named animal climatology. Initiation of research in animal climatology in India was made in 1942 by late Dr. F. C. Minett, the then Director of the IVRI and a number of field investigations have since been made. An important research on the physiological reaction of the male and female cattle of Sindhi, Sahiwal, Tharparkar, Gir and Hariana breeds to hot humid climate is in progress at Haringhata, West Bengal, since 1952. This study includes observations on the climatic effect on various reproductive functions of both the male and the female.

Field investigations in climatology, though very valuable, have their limitations as the different components of the climate are in a state of continuous flux in nature and cannot be held under control in the field. Interpretation of results, therefore, often becomes difficult and sometimes impossible. Critical laboratory experiments can only be performed in a psychrometric chamber where the climatic elements can be controlled as desired. An animal climatology laboratory fully equipped with an elaborate psychrometric chamber is now nearing completion at the IVRI. An extensive programme of research in animal climatology both in the field and in the laboratory has been drawn up. It is hoped that with progress in this research programme, considerable information will be added to our knowledge on the relationship of the climate and the reproductive function of farm animals in India. The studies will also help in determining the suitability of various breeds for the different climatic regions of the country.

With the introduction of AI in the country, investigation on certain aspects of male reproductive physiology of Indian farm animals was inevitable and some informations, though very scanty have now been gathered in this field. The situation regarding the knowledge on the female reproductive function of Indian farm animals is no better than in the male. The little information that is available is presented here.

REPRODUCTION IN THE FEMALE

AGE AT PUBERTY AND AT FIRST CALVING

The animal breeder is interested in getting his cow in calf as early as possible without impairing the subsequent reproductive or productive life of the animal and hence information on the age at puberty and maturity is of great value to him. It is generally believed that heifers of Indian breeds mature much later than those of European breeds. Sufficient information, however, is not available on this aspect. Kumaran (1951) has reported the average age at first oestrus for Tharparkar and Sahiwal cows at Delhi as around 22 months and Ahuja (1957) for the Hariana at Izatnagar as 31 months. Bhattacharya (1953) reported that Murrah buffalo heifers at Izatnagar exhibited first oestrus at an average age of 34 months.

The average age at first calving was reported as 32 months for Tharparkar and Sahiwal breeds at Delhi (Kumaran 1951), 53 months for Hariana at Hissar (Sharma *et al* 1951), and 44 months at Izatnagar (Luktuke 1957), 44 months for Red Sindhi at Hosur and Allahabad (Rajagopalan 1952, Sunderasen 1954), 45 months for Kankrej at Anand (Patel 1956) and 48 months for Kangayam at Hosur (Rajagopalan 1952). The average age at first calving has been reported to be 47 months for Murrah buffaloes by Sunderasen (1954) from Allahabad. Ashfaq and Mason (1954) have also reported 47 months as the age at first calving for buffaloes at Bahadurnagar farm in W. Pakistan while Alim and Ahmed (1954) have given the figure of 39·4 months for buffaloes in Egypt.

It should be made clear here that the methods of investigation for the findings mentioned above, were not uniform and also the husbandry practices were different in the different farms. When the same breeds were studied at different farms there were strain differences. It is, however, very obvious that whereas the cows of European breeds calve when they are little over 2 years old, the cows of Indian breeds have been found not to calve usually earlier than 3 years.

OESTRUS, OESTROUS CYCLE, OVULATION, FERTILIZATION AND GESTATION

When the bull is run with the cow, the breeder need not trouble himself about the duration of oestrus in the female. But, for handmating or AI, accurate information on the duration of the oestrus is essential for ensuring high fertility as the event of ovulation is related to phases of oestrus. In cows, ovulation occurs about 12 hours after the termination of heat and in ewes and sows towards the end of heat. The duration of oestrus in Amritmahal, Sahiwal and Tharparkar breeds of cattle was studied by Kumaran (1951) and was reported to vary from 4-21 hours. The period seemed to be shortest in Sahiwal ranging between 4-15 hours. Information on the Kankraj cattle was gathered by Patel (1953) by observations on over one hundred oestrous cycles during two-year period in a very small number of animals. The mean duration of oestrus found by him was little over 12 hours. He also noted that oestrus lasted about an hour longer in the cow than in the heifer. The average duration of oestrus in the Hariana breed was observed by Ahuja (1957) to be 19 hours in heifers and 23 hours in cows. He found that the heat symptoms were more pronounced in the latter. The average length of oestrus in Murrah heifers at Izatnagar was found to be 29 hours with a wide range of 24-72 hours (Bhattacharya 1953).

The advent of the first post-partum heat in Hariana cattle has been found to occur, on an average, 90 days following parturition (Luktuke 1957). It was observed by Rao and Murari (1956) that in Murrah buffaloes in Andhra, the post-partum oestrus occurred, on an average, 87·7 days following parturition. In Egypt, this interval is 43·3 days (Hafez 1954). According to Hammond (1927) the occurrence of post-oestrous bleeding is fairly common in European breeds of cattle. Trimberger (1941) and Weber and coworkers (1948) have reported this incidence to be as high as 70-80%. Post-oestrous bleeding is not common in Indian cattle. In 221 oestrous cycles studied in 6 heifers and 6 cows of Hariana breed, Ahuja (1957) observed this phenomenon only in two cases—once in a cow and once in a heifer. In the same breed the incidence of oestrus during pregnancy has been found to be 5·8% at Izatnagar.

Domesticated cows are polyoestrous animals and breed throughout the year. After attainment of puberty, the oestrous cycle keeps repeating regularly if pregnancy does not intervene. From few observations in Kankrej and Hariana cows carried out at Anand and Izatnagar respectively, the average length of the oestrous cycle has been found to lie between 17 to 21 days (Patel 1953, Ahuja 1957). In the Kankrej breed long oestrous cycles were followed by short oestrum and vice versa. In the Hariana, regular oestrous cycles were established, on an average, 148 days after the appearance of the first oestrum. The average length of oestrous cycle in Murrah buffaloes was found to be 19·3 days at Izatnagar (Bhattacharya 1953) and 22·9 at Waltair (Rao and Murari 1956).

An isolated study has been made by Rao (1954) on the morphology of the buffalo ova. He found that the average size of the vitellus and the internal and external diameters of Zona pellucida in the case of 18 fertilized ova was 125·50, 146·76 and 176·57 microns respectively. The corresponding figures for 26 unfertilized ova observed were 125·46, 136·10 and 169·35 microns.

By palpating the ovaries in Hariana cows, Ahuja (1957) has concluded that the incidence of ovulation in the right ovary was 57·9% in heifers and 60·5% in cows.

In one of the experiments with buffaloes, Rao (1954) had observed that the maximum number of fertilized ova was recovered from animals in which inseminations were carried out between 24 hours before and 10 hours after the termination of oestrus. He also noticed that spermatozoa survived in the female reproductive tract of the buffalo for 36—48 hours.

Knowledge on the gestation period is important both from the management as well as nutritional points of view. Relatively more informations have been collected on the gestation length of Indian cattle and these are also based on larger number of observations. In one study at Izatnagar, more than twenty thousand records from thirtythree different farms in undivided India for 13 pure breeds and 4 grades and crosses were analysed. The pure breeds studied included Sahiwal, Sindhi, Tharparkar, Gir, Hariana, Kankrej, Ongole, Kangayam, Rath, Amrit Mahal, Hallikar, Bhagnari and Mewati. On an average, the gestation period was found to lie between 280-290 days. The shortest gestation period was noticed in the Red Sindhi and the longest in the Hallikar. Observations by Littlewood (1937) on Ongole and Kangayam, by Dave (1950) on Red Sindhi, by Chaudhuri and Sinha (1951) on Tharparkar, by Sharma and others (1951) and by Kohli and Suri (1957) in Hariana, and by Lazarus and Ananthakrishnan (1952) on Red Sindhi, Gir and Cross-bred cows also gave similar figures. The gestation period in buffaloes has been found to be somewhat longer than in cows (Dave 1940, Arunachalam *et al* 1952, Rao and Murari 1956) and generally exceeds 300 days with a range of 299-325 days. The gestation length in cows is extended one or two days when a male foetus is being carried (Bhattacharya and Prabhu 1952, Kohli and Suri 1957). Lazarus and Ananthakrishnan (1952) and Kohli and Suri (1957) have noted that the sire had a significant effect on the length of gestation and Chaudhuri and Sinha (1951) expressed the view that the age of the cow at the time of calving affected the length of the gestation period.

SEX-RATIO, TWINNING AND MULTIPLE BIRTHS

The secondary sex-ratio of normal births and the incidence of twinning and multiple births in cattle were investigated by Bhattacharya and collaborators (1956a,b) by analysis of more than twentytwo thousand records collected from fortyone farms all over India before partition. The overall secondary sex-ratio was found as 50·8 males to 49·2 females. The percentage of male births for draft, milch, dual-purpose and crossbred (*B. taurus* × *B. indicus*) animals were 51·1, 51·3, 49·7 and 51·2 respectively. Order of gestation, location of the farm, season and their interactions appeared to exert no marked effect on the sex-ratio. Earlier, Brandford (1917) had reported a birth rate of 51·0% males in certain Indian milch breeds from his studies on 7642 birth records. Rao and Murari (1956) found a sex ratio of 51·1 males to 48·9 females in buffaloes at Waltair.

The incidence of twin and triplet birth was found to be 0·22% and 0·004% respectively of the normal births (Bhattacharya *et al* 1956b). Births of more than three calves at a time have not been recorded. The twinning rate in Indian cows seems to be definitely lower than in European cattle which according to Johansson (1932) was 1·88% for dairy breeds.

EFFECT OF SEASON ON REPRODUCTIVE FUNCTION IN FEMALES

As in males, the reproductive function of the female is also affected by seasonal changes. It is well known that some species, like sheep and horse, breed only during certain seasons of the year. Cows breed all through the year but it is beginning to be appreciated that in this species also the efficiency of reproduction varies during different seasons of the year. Hammond (1927) had noted that in England the length of oestrus was shorter in winter as compared to summer, and that the incidence of calvings varied in different seasons. He found that maximum number of cows calved in spring and minimum in autumn months. In Australia, lower fertility has been observed in cattle during the part of the year when the air temperature is high. Patel (1953) at Anand noted that the duration of oestrus was longest in spring and shortest during autumn in Kankrej cattle. A positive significant correlation between duration of oestrus and daily hours of sunshine, and a negative correlation between oestrous length and air humidity were also observed by him. Similar seasonal effect on oestrus was noted by Ahuja (1957) at Izatnagar in Hariana cattle. According to him the ovarian activity seems to be the highest during spring. Similar to observations of Hammond in England, Sikka (1931) noticed that of the annual calvings in cows at the Military Dairy Farm, Ferozepur, the percentage varied in different seasons. The percentage went on increasing regularly from October to March and from March on to September there was a steady decline. The largest percentage was in March (16·01%) and the lowest in September (3·30%). Sharma and coworkers (1951) reported same trends in Hariana cattle at Hissar. Highest percentage of calvings there occurred during March (15·1%) and the lowest during October (4·3%). Joseph and Dave (1931), however, did not notice any seasonal difference in calving incidence in Sahiwal cows at Pusa.

Luktuke (1957) in his studies on buffaloes observed that animals which calved during autumn and winter showed first post-partum oestrus after 50-60 days of parturition whereas those calving in spring after an interval of 100-120 days. The period between calving and first fertile heat was found to be 80-90 days in animals calving in autumn and winter and 150 days in those calving during spring.

From evidence that is accumulating there are reasons to believe that the seasonality in the reproductive function of buffaloes in India is more pronounced than in the cow. Arunachalam and coworkers (1952) at Bangalore found calvings of Murrah buffaloes to be most frequent during October and November and least during February and April. Rao and Murari (1956) observed similar trends in Murrah buffaloes at Waltair. They noticed that only 16% of calvings occurred during September to December. In studies on sexual activity of buffaloes in Bareilly, under village and under better managed farm conditions, De (1957) has observed that of the total number of oestrus recorded, about 80% were during October to March and only about 20% during April to September in both the groups. He also noted that the period of lower sexual activity coincided with higher air temperature and higher relative humidity. It may be mentioned here that the climate alone might not have been responsible for all these seasonal variations reported as other factors like changes in nutrition and husbandry practices might also have contributed to these differences.

* * *

INDUCTION OF OVULATION AND OVA TRANSPLANTATION

Ovaries of a new-born calf contain about 70,000 ova but there is hardly a cow which produces more than a dozen young in its lifetime. Developments of methods for inducing ovulation, super ovulation and ova transplantation offer possibilities of preventing this wastage of innumerable ova, many of which are of excellent genetic make-up. It has now been established that it is possible to induce ovulation in cattle by the administration of gonadotropic hormones and that the status of the ovary and the dosage of the hormone would determine the number of ovulations. It has further been found that superovulated ova are fertilizable (Zawadowsky and Eskin 1939). With administration of 1500-5000 I.U. of PMS upto 5 and 3 days before and after the expression of corpus luteum upto 30 ovulations were obtained in the cow by Hammond and Bhattacharya (1944) at Cambridge. Some of these treated cows were bred and left to calve and two sets of twins and two sets of triplets were born. Later, Dowling (1949) from the same laboratory observed that administration of 3000 I.U. of PMS by injection in the follicular phase of oestrous cycle caused multiple ovulations. The maximum number observed was 51 with an average of 15. This dose caused overstimulation of the ovaries in many cases giving rise to accelerated passage of the ova through the Fallopian tubes. Dowling also noticed that if 100 mg. of horse pituitary extract was injected subcutaneously for 3 consecutive days during the follicular phase, there was, on an average, 6·5 ovulations and 90% of the ova released in this manner were fertilizable. He considered this reaction completely within physiological range because of high rate of fertilization of the ova and thought this to be the most satisfactory method for induction of superovulation in cows. These results led to exploration of the possibility in cattle of ova transplantation, the success of which was demonstrated by Heape in 1890 in rabbits. Whereas in rabbits healthy normal young have been obtained from 80% of the transplanted ova (Hammond 1953), the success so far achieved in cattle is still very limited. Only three live calves have so far been obtained from transplanted ova. This successful result was obtained by Willet and coworkers (1953) at Wisconsin but they had to sacrifice the donors for collecting the ova and perform laparotomy on the recipient for transplantation. It will, therefore, be seen that ova transplantation in cattle is still not practicable on a large-scale basis. Active researches are at present underway at Cambridge and Minnesota in perfecting a suitable technique for collection and transplantation of ova without major surgical intervention. It has been found possible to keep fertilized rabbit eggs alive for four days outside the body and to transport them across the Atlantic by air for successful transplantation (Marden and Chang 1956). When ova transplantation becomes a practical proposition in cattle, there will be enormous speeding up in its genetic improvement. This technique is of special interest to our country where there are very large number of degenerate cattle and a very few good ones. Imagine the progress which is possible if the uterus of the innumerable genetically poor cattle can be made to serve as 'incubators' for fertilized eggs from genetically superior animals.

Attempts were made by Luktuke and Bhattacharya (1948) to induce ovulation in heifers and cows with subactive ovaries by the administration of PMS in doses varying between 1000-2000 I.U. Oestrus was induced in most of the animals within 2-4 days of administration of the hormone, and ovulation occurred in majority of the cases. Only in one animal, twin ovulation was obtained. Pregnancy also resulted in the majority of the animals that were mated following the administration of the drug. These workers also used PMS in doses varying between 750-6000 I.U. in buffalo cows, heifers and immature female calves (Luktuke and Bhattacharya 1953). The hormone was administered during anoestrus, different phases of oestrus and during early phases of pregnancy. All the animals that exhibited oestrum were artificially bred. Among the animals treated during the follicular phase, superovulation up to 10 in number was observed. Out of 24 ovulations in this group, 16 ova were recovered and

87·5% of them were found fertilized. In animals treated during the luteal phase, shortly before the removal of the corpus luteum, most of the recovered ova were unfertilized. There was extensive follicular growth but no ovulation when PMS was administered during mid-oestrus and corpus luteum was not enucleated. Exploratory work on ova transplantation has lately been taken up at Izatnagar.

I have endeavoured in this address to narrate, in brief outlines, some of the research and developmental activities on reproduction in farm animals which have been or are being carried out in different places in India. It will be noticed that vast gaps exist in our knowledge in practically every sphere of these activities, but these will have to be bridged in order to make our farm animals 'giver of plenty' instead of 'giver of scanty' which they are at present.

CONCLUSION

India possesses an enormous population of livestock totalling over 360 millions of which over 155 millions are cattle and 43 millions are buffaloes. The numerical strength of the bovine population of our country is very impressive indeed, but when one tries to take a realistic view of the situation the picture at once becomes extremely gloomy. The productivity of our cattle is one of the lowest in the whole world. For example, the average milk yield of an Indian cow in a lactation is a meagre 413 lb., against the average yield of 5,559 in Netherlands, 5,326 in the U.S.A., 5,517 in the U.K., and 5,742 in New Zealand. The best lactation reported in Holstein Friesian cow has been 45,081 lb., against 13,123 lb., given by the Sahiwal cow Chansuri at the Indian Agricultural Research Institute, New Delhi. The working capabilities of our bullocks have much scope for improvement. The position regarding the other species of livestock is also no better. Our sheep produce only about 2 lb. of wool per head per year, whereas Merino or Rambouillet produce as much as 15-30 lb. In spite of the shockingly low productivity, the contribution of livestock to our national income is enormous and has been estimated by Datta (1953) to be as much as Rs. 3,500 crores annually. If such a valuable contribution is being made by the livestock industry even in its present pitiably neglected condition, it can be well imagined how much more could be derived from our animals with better care and attention.

The improvement of livestock in India would demand elimination of a very large number of uneconomic stock and improvement in the genetic quality in the rest accompanied by better measures of feeding, management and diseases control. In the case of cattle, which is by far the most important farm animal in India, elimination by slaughter is not now possible in many States. This has further aggravated the problem.

To ensure proper economy and to get the best out of our stock, it is essential that the reproductive functioning of the better animals is exploited to the maximum possible limit. To fulfill this need, it is necessary to gather much more knowledge on the process of reproduction in our farm animals, and on ways and means of improving their fertility. In the search for knowledge in this field, very little has been done so far and vast remains yet to be done. One of the main reasons which has hampered progress in this field is the lack of suitably trained personnel for tackling the numerous problems which await investigation. Greater emphasis is needed in the Indian universities like their counterparts in the U.S.A., and the U.K., and many other countries for turning out more specialists in the field of animal reproduction. Besides gathering basic information on physiological norms of various aspects of reproductive process in Indian farm animals, intensive research on the fundamentals of various aspects of reproductive phenomena is an urgent necessity. We have, in India, several species of farm animals and many breeds within a species, as for example, in cattle there are as many as 32 different breeds. There is also a great diversity of climatic pattern in different regions of the country and animal husbandry practices vary a great deal. We do not know the effect of all these variants on the reproduction of the animals. A great deal of fundamental research remains to be undertaken on spermatogenesis, sperm morphology, biophysics and biochemistry of spermatozoa and semen, sperm metabolism both in the male and female reproductive tracts, on the phenomenon of oestrus and oestrous cycle, oogenesis, ovulation, fertilization, ovum metabolism, ovum implantation, gestation and parturition. Much yet remains to be unravelled regarding the intricacies of endocrine involvement in reproduction and animal sex-behaviour. A good deal has also to be done about the study of the organizational aspect and how best the knowledge gathered in the laboratory can be fully utilized under field conditions.

To gather a more elaborate and integrated information on the subject, greater collaborative efforts between scientists of various disciplines like zoology, physiology, microbiology, biochemistry, biophysics, statistics, animal genetics etc., is necessary. Until this is done, it is not possible to harvest the best benefit out of the animal industry. Not many zoologists in India have so far paid much attention to the field of farm animal reproduction. Perhaps, this has been due to the various limitations enforced by conditions in which they have to work. Their valuable experiences and service towards the solution of many vexed problems in this interesting and important field will be most welcome by animal husbandry workers. There are many fundamental aspects in 'physiological zoology of reproduction' in which the zoologists can play an important role. The search for truth for its own sake hardly ever goes in vain. In all scientific disciplines, fundamental research has provided the root for applied benefit in future.

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SECTION OF ANTHROPOLOGY AND ARCHAEOLOGY

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VARIATION IN MAN

Hegel analysed progress into three stages, which he called Thesis, Antithesis, and Synthesis. In applying this idea to educational theory A. N. Whitehead adopted the terms, Stage of Romance, Stage of Precision, and Stage of Generalization. Thinking in these terms of stages of progress one is likely to get an impression that such stages are discrete and separate, one following the other. But this may not be so. It may be possible that each stage of progress may have the seeds of the other two inherent in it. This method of analysis of progress can be applied to the growth and progress of science.

Science of Anthropology deals with all mankind in its environment. It tries to understand ourselves, here, now, so that it may help to improve our present, and possibly influence the future. It concerns itself with men's physiques, their societies, with communications and products—the languages and culture—of these societies. It has so far specialized on the primitives, because no other science will deal seriously with them.

If one were to apply Whitehead's idea of stages of progress, then it looks that Anthropology of today is in the stage of Precision. Some few generalizations are in sight. The strategy of Physical Anthropology—as Washburne describes—is fast changing. Anthropologists have not yet finalized their new method. This is so because purpose and theory are also undergoing a radical change. The emerging new Anthropology is gradually tending to be a coordinating science. Concept of "Culture", around which various disciplines like Psychology, Biochemistry, Primatology, Genetics, Anatomy etc. are closing round, is the centre. Clearer definitions of Culture are being attempted at. One such by Jules Henry is comprehensive and clear, having been expressed on physiological basis. This is dealt with later.

The research activity in Anthropology in future must become a collective and integrated activity of scientists drawn from different disciplines. So far we are accustomed to seeing a lone anthropologist doing some research. This is going to be a thing of the past.

With this background, I now make an attempt to present to you in this address the following three topics.

1. The nature of the methodic exposition of "Variation in Man" by ancient Indians (600-500 B.C.) as hypothesized by them. It is significant to note that these exponents were mainly the pioneers in Ayurveda—Science of life—and practised medicine in India of Ancient times.

2. Tendency of Anthropologists towards the progressive utilization of important newly developed biological and other sciences in an anthropological investigation.

3. Realization of the positive usefulness of New Anthropology to reorient the health organizations and concepts of disease, somewhat on the lines of what Ancient Indians attempted.

1. EXPOSITION OF VARIATION IN MAN BY ANCIENT INDIANS

The following information regarding variation in man as expounded by ancient Indians, is collected from Carakasaṁhitā, Suśrutasaṁhitā, Aṣṭāṅgasaṅgraha etc. which are considered authorities in this regard.

The study of normal man was used by Ancients:

1.1. to differentiate Ātura (a patient) from a person of normal health,

1.2. to know suitability of man and woman to each other in mating,

1.3. to know the past and future of man.

1.1. For examination of a patient, Caraka lays down a rule that Ātura should be examined, with a view to find out his

1.1.1. Prakṛti—Normalcy (there is no correct English word equivalent to the idea underlying the Sanskrit word Prakṛti),

1.1.2. Vikṛti—Disturbance of normalcy,

1.1.3. Sāra—Essences (dominances?),

1.1.4. Saṁhanana—Body build,

1.1.5. Pramāṇa—(body) proportions,

1.1.6. Sātmya—Likes and dislikes,

1.1.7. Satvaśakti—Power of mind,

1.1.8. Vyāyāmaśakti—Capacity for physical work,

1.1.9. Āhāraśakti—Eating and digesting capacity,

1.1.10. Vayas—Age.

1.1.1. Prakṛti (normalcy) is determined in its following 4 aspects:

1.1.1.1. Prakṛti of a person may be of 3 types according to which of the 3 body humors (Vāta, Pitta, Kapha) is dominating in him.

1.1.1.2. Normalcy is influenced by the following factors.

1.1.1.2.1. Jātiprasaktā—attached to caste.

1.1.1.2.2. Kulaprasaktā—attached to lineage of family.

1.1.1.2.3. Deśanupātini—consequent to the region (of land).

1.1.1.2.4. Vayonupātini—consequent to age.

1.1.1.2.5. Kālānupātini—consequent to weather.

1.1.1.2.6. Pratyātmaniyatā—restrained by one's own self.

1.1.1.3. Varṇa—complexion. They are 4. Kṛṣṇa (dark),
Śyāma (brown), Avadāta (spotless fair),
Śyāmāvadāta (spotless brown),

1.1.1.4. Swara—Voice resembling, any of the following:
Hansa (swan), Krauñca (heron), Nemi (ring of wheel), Dundubhi (large kettle drum), Kalaviṅka (sparrow), Kāka (crow), Kapota (dove), Jarjara (dull hollow broken brass vessel). There are 8 types.

1.1.2. Vikṛti—Malconditions. These are dealt with, in Indian Medicine.

1.1.3. Sāra—Essences, or dominant peculiarities of a person, consisting of 8 types.

1.1.3.1. Tvaksāra—Skin essence or dominance. Skin is juicy, smooth, soft, and pleasant. Hair are soft, long, delicate, and lustrous.

1.1.3.2. Raktasāra—Blood essence or dominance. Ears, eyes, mouth, tongue, nose, lips, palms, soles, nails, forehead, penis are red and lustrous.

1.1.3.3. Mānsasāra—Flesh essence or dominance. Temples, forehead, upper part of neck, orbits, cheek, jaws, shoulders, belly, chest, joints or hands and feet are bigger and full of flesh. These persons are strong, have courage, are happy and straightforward, have push and forgiving temperament.

1.1.3.4. Medahsāra—Fat essence or dominance. Skin, hair, nails, lips, teeth, urine, and stools are oily. These persons have endearing eyes, and voice is affectionate. They are delicate and need sympathetic treatment.

1.1.3.5. Asthisāra—Bone essence or dominance. Heels, ankles, knees, wrists, sternum, cheeks, head, joints, nails, teeth, and bones in general are big. These persons are strong, active, and have great capacity for bearing pain. They are energetic.

1.1.3.6. Majjāsāra—Marrow essence or dominance. These persons are strong, have soft body and big joints. They beget many issues.

1.1.3.7. Śukrasāra—Semen essence or dominance. These are mild persons. Their eyes are mild with a mild look. They have evenly set teeth, pleasant skin, and have an attractive voice full of affection. They have big loins. They are jolly, healthy, and fond of women. They love popularity. They beget many issues.

1.1.3.8. Satvasāra—Mind essence or dominance. These persons are devoting, grateful, and learned. They are alert, bold, and great fighters. They have great energy. They have strong memory, and like serious intellectual pursuits for the good of the people. They have clean habits, and their gait is sound. They do not mourn losses.

A person may belong to one or more essences. Persons not coming under any of the above categories are Asāra (without essence).

1.1.4. Saṁhanana—Body build. There are three types:

1.1.4.1. Susaṁhata (well built). Body symmetrically disposed, bones strong, joints secure, flesh well placed, and full blood are the characteristics of this type. These are Balavanta (powerful).

1.1.4.2. Visaṁhata (weakly built). Type opposite to susaṁhata. These persons are Alpabala (not much powerful).

1.1.4.3. Madhyamasaṁhata (medium built). Medium type between Susaṁhata and Visaṁhata, with medium power, Madhyamabala.

1.1.5. Pramāṇās (proportions) of human body. These are quoted from

(a) Carakasaṁhitā—Vimānasthāna, Adhyāya 8,
(b) Suśrutasaṁhita—Sūtrasthāna, Adhyāya 35,
(c) Aṣṭāṅgasangraha—Śarirsthāna, Marmabhedīya Adhyāya 8.

These are normals.

The method of taking measurements for pramāṇās is given below :—

देहः स्वैरंगुलैरेष यथावदनुकीर्तितः ।
युक्तः प्रमाणेनानेन पुमान् वा यदि वांऽङ्गना

(Suśrutasaṁhitā, Sūtrasthāna, Adhyāya 35, Śloka 14).

> "Measured by fingers of the body to be measured, if the body of a male or a female has the proportions as described, then he or she should be considered, as having a correct proportionate body."

It need not be mentioned that measurements by fingers, are really phalango-corporal indices, and not absolute measurements.

	Body Parts	Fingers		
		Śruta	Caraka	A. Saṅgraha
1.	Length, big toe	2	—	2
2.	,, 2nd toe	2	—	2
3.	,, 3rd toe	8/5	—	8/5
4.	,, 4th toe	32/25	—	32/25
5.	,, 5th toe	1	—	1
6.	,, total foot	14	14	14
7.	,, leg	18	18	18
8.	,, from knee to waist	32	—	—
9.	,, total, lower limb	50	—	—
10.	,, thigh, knee to hip joint	18	18	18
11.	,, knee	—	4	4
12.	,, calf belly	—	10	10
13.	,, forefoot	4	—	4
14.	,, foot central part	4	—	4
15.	,, heel	5	—	4
16.	Breadth, forefoot	5	—	6
17.	,, foot central part	5	—	5
18.	,, heel	4	—	4
19.	Circumference, foot central part	14	—	14
20.	,, ankle	14	—	14
21.	,, leg central part	14	—	14
22.	,, knee	14	16	—
23.	,, calf belly	16	16	—
24.	,, thigh	32	32	32
25.	Height, arch of the foot	—	4	4
26.	Length, testis	2	—	—
27.	,, non-erect penis	4	6	—
28.	,, vagina	12	—	—
29.	,, scrotum	—	6	6
30.	Circumference, vulva	—	12	—
31.	,, scrotum	—	8	8
32.	,, penis	—	5	—
33.	Width, chin	2	—	—
34.	,, chin and lip together	—	4	4
35.	,, side of the nose	2	—	—
36.	Length, tooth	2	—	—
37.	,, nose	4	4	4
38.	,, ear	4	4	4

	Body Parts	Fingers		
		Suśruta	Caraka	A. Saṅgraha
39.	Length, eye	—	—	2
40.	,, nasal opening each ...	1⅓	—	—
41.	,, face	12	12	12
42.	Breadth, forehead	4	4	4
43.	,, open eye	—	—	breadth thumb
44.	Distance, between eyes	2	—	—
45.	,, ,, ear and outer canthus ...	5	—	—
46.	,, ,, hinder border of the left auricle to that of the right ear across face ...	24	24	24
47.	Distance, between pupils ...	4	4	4
48.	Mouth fully open	4	5	5
49.	Corneal surface proportion of eye ...	1/3	—	1/3
50.	Pupil, proportion of cornea ...	1/9	—	1/9
51.	Distance, from hair line to vertex ...	11	—	—
52.	,, ,, vertex to back hair line	10	—	—
53.	,, between ear to ear on head back	14	—	—
54.	,, between upper end of neck to vertex	—	16	16
55.	Circumference, head	—	32	32
56.	,, neck	24	24	22
57.	Nape of neck, (upper end of the trunk to the bottom of head) ...	4	4	4
58.	Heart beat area to neck in front ...	12	—	—
59.	Distance between nipples ...	12	12	—
60.	Length, chest surface	12	12	—
61.	Breadth, chest surface	—	24	—
62.	Areola, breast	—	2	—
63.	Heartbeat area	—	2	2
64.	Length, whole arm excluding axillary region	32	—	—
65.	,, upper end of humerus to elbow	16	16	16
66.	,, shoulder joint	—	6	6
67.	,, axilla	—	8	8
68.	,, hand	—	12	12
69.	,, middle finger	5	—	5
70.	,, index and ring finger ...	4½	—	4½
71.	,, thumb and little finger each	3½	—	3½
72.	Distance root of thumb to index finger	5	—	—
73.	,, elbow tip to middle finger tip	24	—	—
74.	,, between palm and elbow ...	16	15	15
75.	Circumference uniform between root of hand and a point four fingers above it	12	—	—

Body Parts	Fingers		
	Suśruta	**Caraka**	**A. Saṅgraha**
76. Hollow of the palm	6 by 4	—	—
77. Distance between umbilicus and root of penis	12		
78. Length, udar (belly) surfacial ...	—	12	12
79. Width, udar (belly) surfacial ...	—	12	12
80. Length, waist	—	16	16
81. Circumference, waist	—	—	50
82. Expanse of a shoulder	—	8	8
83. Sides, chest up to axilla, length ...	—	12	12
84. Sides, chest up to axilla, width ...	—	10	10
85. Height, pelvis while sitting ...	—	12	12
86. Distance from upper border of pelvis to beginning of neck on the back	—	18	—
87. Stature	20	84	84
88. Arm stretch	—	84	—
SEX DIFFERENCES			
89. Female hip region as broad as male chest	24	—	—
90. Female chest as broad as male waist	18	—	—

Suśruta further says that these proportions can only be applied to the males above 25 and females above 16 years.

Stature (87) is described as 120 fingers by Suśruta, and 84 fingers by Caraka and A. Sangraha. This disparity is due to the reason, as mentioned by Dalhana the commentator of Suśrutasaṁhitā, that Suśruta's stature is taken with the arms raised above the head.

1.1.6. Sātmya—Likes and dislikes.

1.1.6.1. Ghṛta-kśhīra-taila-mānsarasa Sātmya—persons who are fond of ghee, milk preparations, oils, and meat juices. These are strong, bear pain, and have long life.

1.1.6.2. Ruksha Sātmya—are persons who like rough food. These cannot bear pain, are weak, and have short life.

1.1.6.3. Vyāmiśra Sātmya—persons with mixed likes, get mixed consequences.

1.1.7. Satvaśakti—power of mind. (1.1.3.8. is further analysed here)

1.1.7.1. Pravara-satva are persons who can bear any pain lightly.

1.1.7.2. Hīna-ṣatva are persons who cannot bear pain, and cannot be consoled also. Very little physical pain upsets them. Sights of ugly things, terrifying experiences, sight of blood, flesh etc. completely upset them. They may collapse, faint, become demented, and may even die, in the above mentioned circumstances.

1.1.7.3. Madhya-satva persons are of intermediate type, and can bear pain by thinking, can control themselves by effort, and can be consoled.

1.1.8. Vyāyāma-śakti—capacity for physical work, judged by making a person do graded physical work.

1.1.9. Āhāra-śakti—capacity for quantity of food and digesting it. Four types—

1.1.9.1. Samāhār-śakti—capacity for eating and digesting moderate amount of good food always.

1.1.9.2. Visamāhār-śakti—sometimes eat and digest and sometimes cannot.
1.1.9.3. Atibhukta—can digest huge quantities of food.
1.1.9.4. Alpa-pacanśakti—cannot eat much and have poor digestion.
1.1.10. Vayas—age. This is considered at length, but its description is left out.
1.2. Suitability of man and woman in mating.

In Kāmaśāstra (science of love) man and woman each has been described in two different ways. Their individual characters are described at length. A very brief account is given here.

1.2.1. Types are determined by comparison with animals. Esthetic grouping is based upon general form, shape and beauty.

	Type Man		Type Woman
1.	Mṛga (deer)	Vs.	Padmini (lotus)
2.	Śaśa (hare)	Vs.	Citriṇī (talented, artistic)
3.	Vṛṣa (bull)	Vs.	Hastinī (she-elephant)
4.	Aśva (horse)	Vs.	Śankhinī (conch)

1.2.2. Mating groups are based on physical suitability.

Type Man	Mate of	Type Woman
Śaśa (hare) penis length 6 fingers	...	Mṛgī (doe) vagina length 6 fingers
Vṛṣa (bull) penis length 9 fingers	.	Aśvī (mare) vagina length 9 fingers
Aśva (horse) penis length 12 fingers	.	Karinī (she elephant) vagina length 12 fingers.

1.3. Sāmudrika-śāstra is supposed to be the science of knowing the past and future of man, from observations made on him. These observations are of the following nature:—

उन्मान मान गति संहृति सार वर्ण
स्नेह स्वर प्रकृति सत्वमनूक मादौ
क्षेत्रं मृजाश्च विधिवत्कुशलोऽवलोक्य
सामुद्रविद्वदति यातमनागतंच ॥१॥

(Sāmudrika-śāstra by Vedavyāsa, Śloka 1).

> "Past and future of a person is told by a clever person knowing Sāmudrika-śāstra after having methodically observed height, weight, gait, essences, complexion, oiliness, voice, constitution, mental condition, form and shape of face, the whole body and its parts, and lustre of a person."

Individual variations of each observation are attributed predicting values. Observations are done on: (1) variation in shape, form, and comparison with animals, (2) some visible functional features, (3) Āyurvedic considerations, and (4) lustre.

(1) Body parts observed are feet, legs, knees, penis, scrotum, glans penis, buttocks, waist, abdominal outline, sides of abdomen, sides of chest, umbilicus, skin, skin folds on abdomen, nipples, back, heart area, front of the chest, sternoclavicular junctions, neck, ribs, sternum, shoulders, hands, fingers, wrists, palms, nails, patterns of ridges on fingers, the same on palms, lower jaw, lips, teeth, tongue, palate, face contours, Adam's apple, moustache and beard, cheeks, ears, nose, eyes, eyebrows, temples, forehead, lines on forehead, head, and hair on head.

(2) Some visible functional and other features are observed :
   (a) Urine, nature of urine flow, semen.
   (b) Voice, nature is noted.
   (c) Peculiarities about laughing, weeping, and sneezing are considered.

(3) Variations based on Āyurvedic considerations are noted (1.1).

(4) Lustre of a person is considered.

Two samples of Sāmudrika observations are reproduced here.

परिमंडलैर्गवाढ्याश्छत्राकारैः शिरोभिरवनीशाः ।
चिपिटैः पितृमातृघ्नाः करोटिशिरसां चिरान्मृत्युः ॥११४॥
घटमूर्धा ध्यानरुचिर्द्विमस्तकः पापकृद्धनैस्त्यक्तः ।
निम्नंतु शिरो महतां बहुनिम्नमनर्थदं भवति ॥११५॥

(Sāmudrika-śāstra, by Vedavyās)

"With Parimaṇdala (spherical) heads be rich possessor of cows, with Chatrākāra (umbrella-shaped) heads be lords of earth, with Cipita (flat nosed) heads be killers of father and mother, with Karoti (oval long bowl shaped) heads have long life, with Ghata (Indian pitcher shaped) heads be fond of meditation, with Dvimastaka (bifid) heads be sinner and forsaken by riches, with Nimna (apically narrowing) heads be great, and Bahunimna (extremely apically narrowing) head is the source of disasters."

साध्यमनूकं वक्त्राद्गोवृषशार्दूल सिंहगरुडमुखाः ।
अप्रतिहतप्रतापा जितरुपवो मानवेंद्राश्च ॥१३८॥
वानरमहिषवराहाज तुल्यवदनाः सुतार्थसुखभाजः ।
गर्दभकरभप्रतिमैर्मुखैः शरीरैश्च निःस्वसुखाः ॥१३९॥

(Sāmudrika-śāstra, by Vedavyās)

"It is possible to tell the disposition of a person by observing face. Persons with face forms, of cow, bull, tiger, lion, and eagle types are lords of men, have invincible prowess, and are conquerers of enemies. Persons with face forms of ape, buffalo, sheep, and boar types are happy, wealthy, and beget many issues. Persons with face forms and bodies of ass, and camel types will be always unhappy."

Further, five types of Mahāpuruṣa (big men), and five types of deformed men are described.

Mahāpuruṣa:—1. Malavya are residents of Cutch, Saurastra, Gujrāt, Sind, Mālwā, Mārwār.
2. Bhadra are residents of Central India.
3. Rucaka are residents of Vindhya, Sahya, Ujjain.
4. Śaśa are residents of Mlechha (non-Hindu) country.
5. Haṃsa are residents of Khasa, Sūrsena, Gandhāra, Duab.

Deformed:— 1. Jaghanya (big buttocked) is dull, bold, cruel, humorous.
2. Vāmanaka (pygmy) broken-backed, God-fearing.
3. Mandālaka (white leucoderma spots) fond of learning and black art.
4. Sāmi (very ugly) unlucky, charitable.
5. Kubjaka (hunch-backed) bold, dies suddenly.

Lastly, amongst Hindus there is a belief that an ideal human body has the following 32 Lakshaṇās (signs):—

1. Umbilicus deep and whorling to the right. 2. Voice deep. 3, 4, 5, 6, 7, 8, 9, nails, eye-corners, lips, palate, feet, tongue, palms red. 10, 11, 12, forehead, face, heart broad. 13, nose long. 14, 15, 16, 17, distance between nipples, eyes, jaws, arms long. 18, 19, 20, 21, 22, joints, teeth, skin, nails, hair, delicate and thin. 23, 24, 25, 26, back, penis, legs, neck short. 27, 28, 29, 30, 31, 32, head, neck, mouth, chest, axilla, nose, held up.

All these descriptions, which we have just gone through, display the critical attitudes of obsefvational capacity and ingenuity of thought of Ancient Indian scientists. It is worth noting that various angles concerning variation in man, which in the present era of psychosomatic medicine are the objects of study, seem reflected in the minds of Caraka and Suśruta.

Body measurements and observations (1.1.1.3.) (1.1.5.), heredity (1.1.1.2.1.) (1.1.1.2.2.), body build (1.1.4.), psychological factors (1.1.7.), personality (1.1.6) (1.1.7) (1.1.1.2.6.), eugenics (1.2), attitudes and mental traits correlated to physical variations (1.3), ecology (1.1.1.2.3. & 5) have received their attention. Lastly, essences or dominances of tissues—a novel consideration—may not be so unintelligible to our mind, if we ponder and think. Could not these be considerations, our forefathers probably had in their minds in their own characteristic way, pertaining to typology of integrated genetic traits?

Let me now briefly review the account of newly developing sciences, which are progressively being utilized in Anthropology.

2. UTILIZATION OF NEWLY DEVELOPED BIOLOGICAL SCIENCES IN ANTHROPOLOGICAL INVESTIGATIONS

During the last century and a half, physical variation in man was attempted to be studied and understood by physical measurements. Out of all the measurements utilized for the purpose, "CEPHALIC INDEX" held sway over other mensural estimations. This period can aptly be called as "Cephalic Index Era". Traditional method of this era was speculation. This era is passing. There had been enough speculations and classifications. New methods of investigation are being developed to prove which of the speculations are on the right track. It is true, however, that in studies of growth and applied anthropology measuring rod and calipers will be necessary, as the direct knowledge of dimensions is, what is aimed at. But in the evolutionary investigations, the change of methods and theoretical approach are of greatest importance. Washburn expresses that "much of the old anthropological work on race and constitution is eliminated by rejection of the old concept of type. However, one of the main implications of the new point of view is that there is a far more intimate interrelationship between the different aspects of anthropology than under the old strategy. For example, a dynamic analysis of the form of jaw will illuminate problems of evolution, fossil man, race, growth, constitution, and medical application. An unravelling of the process of evolution and variation will enrich the understanding of other mammalian groups, whereas the detailed description of a fossil has a much more limited utility. By its very nature, the investigation of process and behaviour has a generality which is lacking in purely descriptive studies. The problems of human evolution are but the special cases of the problems of mammalian evolution, and their solution will enrich paleontology, genetics, and parts of clinical medicine."

"Recently, evolutionary studies have been revitalized and revolutionized by an infusion of genetics into paleontology and systematics. The old physical anthropology was primarily a technique. The common core of the science was measurement of external form with calipers. The new physical anthropology is primarily an area of interest, the desire to understand the process of primate evolution and human variation by the most efficient techniques available. The change is fundamentally one of point of view, which is made possible by an understanding of the way the genetic constitution of populations changes. Population genetics presents the anthropologist with a clearly formulated, experimentally verified, conceptual scheme. The application of this theory to the primates is the immediate test of physical anthropology." "Evolution is best understood by thinking of it as always adaptive." Genes are the determiners of characters. Small differences due to single genes accumulate in the course of evolution, the small differences become major differences. When enough gene differences are accumulated or caused by chromosome alterations, a new species emerges. If evolution, essentially, is nothing but a change in gene frequencies, it would be necessary to see the processes of genetic changes.

All of us know that genes have their basic characteristics. A gene has either a dominance over its allele, or is recessive. It mutates. Mutation is a chemical or physical change potentially capable of being transmitted. Mutation in a germinal gene only is what counts for transmission. Most mutations are recessive, and more or less harmful to the organism. Mutation rate in most of the genes is very low. Comparatively genes are stable. Mutation may take place once in thousands of years in a gene. Mutations do not take place in more than one gene at a time. Attempts at producing mutations experimentally by food, humidity, temperature and other environmental factors were unsuccessful. Use of X-rays and other types of irradiation may greatly increase the mutation rate. Genes may get lost by chromosomal deletion or breaking away. Recessive mutations are usually lost.

A second consideration is that, with all these hazards a gene must get a chance of being transmitted, then alone the offspring will be influenced by that gene. And to influence a population, effectively, permanently, gene must get successive similar chances so that its frequency in a population should increase. Such chances would depend on—

1. tendencies of populations in selecting mates,
2. rate of fertility in an individual,
3. size of a population,
4. stable or migrating nature of the population,
5. facilities of mixing up of different populations,
6. isolation of a population.

Thus, genetic study is almost entirely dependent on the studies of populations. There are six major points to be taken into account about the studies of genetics.

1. Unit of study must be the population and not the individual. Because it is the breeding population in which gentics is interested, breeding habits of the group under study must be known. To define population limits, one must look for help to both the ecologist and the demographer.
2. Populations cannot be defined by a survey of single characters. Several attributes of population are important subjects for study.
   (a) Breeding enclaves.
   (b) Increase of contact of populations by means of rapid communications and rapid transportation.
   (c) Increase of population.
   (d) Factors affecting population pressures.
3. Animal experimentation for ecological studies.
4. There is no use in following a combination of traits. Each trait must be traced by itself.
5. Since different approaches yield different racial types, many of the older typological groups will have to be abandoned as the basic unit becomes the population. There should be a shift in emphasis from classification towards that of understanding the processes of race formation. With the genetic method many races could be ruled out as genetically undemonstrable.
6. Genetic classifications of human groups will have to be set up.

Determining a genetic trait

To claim that a particular trait is genetic in origin is a difficult matter. Dr. James Spuhler began his studies by laying down certain assumptions about the rules for changes of genetic characteristics.

A. Neither selection nor mutation has much to do with these changes.
B. No two genes are known to occupy the same locus on the chromosome, so that isolation and identification of genes should not be impossible.
C. To make a satisfactory genetic study the population must neither be too small nor too large.
D. The frequency of the trait must neither be too rare nor too common.

Important genes so far demonstrated

The account of the genetic traits rendered here, is besides the pathological traits which are left out.

BLOOD GROUPS

1. Blood groups, O, A, B, AB, are well known. Later the following subgroups of A were found. A_1 five or six times as common as A_2, A_3 one in 60,000, and A_4 one in 2,000 persons.
2. Later investigations brought forth two other agglutinogens M, N, a Mendelian pair of genes not carried on the same chromosome which carries O, A, B genes. Recently discovered Anti-Sera enable the M, N, groups to be subdivided. The S, s, gene pair might be another pair of alleles linked to the M, N, locus, but it is also possible that the new pair simply enables, instead of the M, N, pair, four alleles MS, Ms, NS, Ns, to be distinguished.
3. P blood groups were discovered nearly along with M and N. The antigen P is inherited as a dominant. Gradation in the strength of P is observed.
4. The ability to secrete blood group substances A, B, and H (Q) into saliva and other body fluids in water soluble form, to be inherited as a Mendelian pair, S (secretor) being dominant over s. The highest frequency for secretor is found among American Negro; the lowest in Amerinds.
5. Lewis blood groups :—L is recessive in adults and dominant in children. L blood groups are found intimately associated with the secreting factor. All adult individuals reacting with anti-Le^a and therefore by hypothesis, Le^a/Le^a genetically, are non-secretors of A, B, and H. Most Le^a negatives are secretors, but about 1% secrete neither A, B, H, Le^a nor Le^b. It is thought that they probably secrete an antigen Le^c, not yet identified. Thus the genes Le^a, Le^b, Le^c, and S, s would form two series of alleles contiguous to each other.
6. Rh factor :—According to Fisher's hypothesis, three closely linked adjacent loci, C, D, E, are involved. According to Weiner's hypothesis a series of allelomorphic genes, r, R', R'', R_1, R_2, R_0, r^y, R^z, are involved. The two theories lead to identical genetic predictions. Other Rh antigens have been found from time to time, so that the following genes are available for the C, D, and E, loci respectively. C, c, C^w, c^v, C^u; D, d, D^u; E, e, E^u. No particular dominance relations are observed among these genes.

   The Rh gene of human blood is turning out to have so many ramifications astounding in nature, that it is difficult to keep pace with these.
7. Lutherian blood groups. The dominant gene responsible is called Lu^a and the still hypothetical recessive gene as Lu^b.
8. Kell blood groups. This antibody is symbolized as K, and its allele as k.
9. Duffy blood groups named after the patient "Duffy" who was suffering from hemophilia and who had several blood transfusions over the preceding 20 years. The gene is named as Fy^a, and the hypothetical allelic gene as Fy^b. An agglutinin for Fy^b was found in the blood of a lady in Berlin after the birth of her second child. The child appeared normal, and the antibody, which had a titer of 16,000 was discovered in the course of routine examination of the sera of all the mothers in the hospital.
10. A still new blood group factor called "Kidd" has been found. Gene symbol "Jk^a" is given to it. Its hypothetical allele is called "Jk^b".

Blood groups offer several advantages in genetic study

1. They are inherited in a known way according to the Mendelian principles.
2. They are not altered by differences in climate, food, illness, or medical treatment.
3. Their frequency in population is stable, as far as the present observations extend.
4. They probably arose very early in the course of man's evolution.
5. There is a considerable correlation between geography and the distribution of the blood groups with the relevant antigenic substances.
6. Blood groups are sharply distinguishable "all—or—none" characters, which do not grade into one another.

HUMAN HEMOGLOBIN

Hemoglobin, the coloring pigment of human red blood cells, is found to be of many types. Pauling and his associates (1949) described sickle-cell hemoglobin and introduced into Medicine the concept of molecular disease. Different types of hemoglobin can be identified by its biochemical properties, reactions in electrophoretic process, and other special methods. Though the genetic study of different types of hemoglobin is not complete, still at present there is a strong evidence that the variations in hemoglobin are genetic traits.

Nomenclature	Types of hemoglobin
Hgb A	Normal adult hemoglobin
Hgb F	Fetal hemoglobin
Hgb S	Sickle cell hemoglobin
Hgb C	....
Hgb D	....
Hgb E	....
Hgb G	....
Hgb H	....

From the evidence available, the human hemoglobin types, with the exception of Hgb F, are controlled by a single set of allelomorphic genes. Hgb F, in contrast to the other hemoglobins, appears to be under the control of an independent set of allelic genes. There is no data to suggest, that the concept of dominance or recessiveness may be applied to the genetics of the human hemoglobins, although the expressivity of genes must vary. All the hemoglobin types appear to inhibit the expressivity of Hgb F in varying degrees—Hgb A to the greatest degree. Increased expressivity of Hgbs S, C, E and F, may in turn inhibit normal adult human hemoglobin formation.

OTHER GENETIC TRAITS

1. Subjective taste traits:—Taste reaction to P.T.C. (phenothiocarbamide) indicates that Amerinds are low in non-tasters Negroes and Caucasians are higher than the Mongoloids in this regard. In connection with the evolutionary significance in taste reactions to such substances as phenylthiourea, Boyd notes that these are phar-

macologically anti-thyroid, and heterozygosity may be of adaptive advantage. Barnicot demonstrates, that nontasters are much rarer among Chinese and Africans than among English.

2. Linguistic studies of issoglosses of "th" in Europe. In respect of this trait about peculiarities of pronunciation of the same alphabet, there is a great field for research in India.
3. Capacity of tongue rolling and tongue folding. The presence of folding depends on rolling. Work is done among Chinese.
4. Longitudinal and transverse patterns of superficial veins as manifest in infra-red photographs (anterior thorax).
5. Presence or absence of palmaris longus muscle in forearm and poronius tertius muscle in leg.
6. Color blindness:—Probably there are several alleles concerned. The frequency of red-green color blindness is lower among Amerinds than among Chinese, Japanese or European populations. There are two types of color blindness (red-green). 4·97% males and 0·71% females from a total of 11,000 Chinese, were color blind.
7. Number and form of circumvallate papillae (found just in front of anterior sulcus of tongue):—Number varies from three to eleven, and the patterns of their arrangement may take the form of either a "V", "Y", "W", or "T". It appears that there are five alleles with dominance of large over small number of papillae.
8. Hair patterns:—Occipital hair whorl is controlled by a single allele with the clockwise whorl dominant.
9. Five allelic genes have been suggested to explain the occurrence of mid-digital hair: There is an apparent preponderance of ring finger mid-digital among Nordics and Iranians. Middle finger among Alpines, index finger among Slavic countries, and the little finger in Ireland.
10. Dermatoglyphics:—Three pairs of single alleles are identified, one each for the pattern of epidermal pad, one for anlage, for the radial pattern and for radial thickness.
11. Is there any correlation (genetic) between pigmentation and blood groups O and A?
12. Polydactyly (more than five digits), syndactyly (fingers bound together), and clinodactyly (congenital abnormal deflection of fingers or toes).
13. Deafness.
14. Absence of teeth.
15. Visceral asymmetry.
16. Somatometric relations between relatives of the first degree.
17. Twins study:—Frequency of monozygous twins confinement appears to increase with the age of the mother. There is the same frequency of reactions to small-pox in monozygous and dizygous twin pairs. Digital prints, beginning walking, dentition, stature, weight, hair form and color, and eye color are said to be more or less frequently discordant (in 51 pairs). Ossification of carpals and of costal cartilages is used as a criterion of zygosity. Discordance in dental occlusion in a pair of monozygous twins is referred to mechanical factors operating in one of the pairs. Kallman has applied twin studies to the problems of ageing and mental disease, and notes the possible importance of differences in other factors, such as weight, in monozygous pairs discordant for schizophrenia. In assessing the role of environmental factors in

man, studies of identical twins provide one method of controlling genetic factors. Sterility, left-handedness, height, weight, hair and dermatoglyphics, etc., can give useful information by studies on identical twins. Rearing of identical twins in different environments and studies undertaken on them will throw much light on influences of environment. Price suggests that the results of many twin studies may have been interpreted wrongly because of failure to distinguish monochorial from dichorial types of monozygous pairs.

HUMAN ECOLOGY

In studying the relation of the individual to his environment, the individual should be studied in totality, and his environment be conceived of as the universe around him. In studying ecological factors, some of the problems of approach have to be tackled. Genetic study has to be tackled through population studies, and population studies in turn are closely associated with environmental studies. Some problems of *Human Ecology can be considered here.

1. Whether, in the study of human ecology, the distinction commonly made between population and community is valid.
2. It would be necessary to study the effect of each of the several elements on selection and adaptation of the human organism. The particular elements to be taken into consideration would be climate, altitude, nutrition, migration, density of settlement, and the uses of the natural resources made by man, as fertile fields for coordinated investigation.
3. The influence of social organization on biological make-up of a population might be approached with an ecological slant. Mating patterns are obviously amenable to investigation, but other social factors can also have biological effects: as for example, life under a surplus or subsistence economy.

   Different phenotypic end-products may result from a differential development of the organism during child rearing,—the factors such as differences in degree and kind of physical activity at an early age—i.e. ability to swim—as opposed to cultural emphasis on mental activities.

   In regard to nutrition and disease the social organization also has an effect on the biological end-product.
4. Human ecology serves to keep in focus two of physical anthropology's most fruitful concepts: those of function and of population. It can serve therefore as a framework for the study of such problems as the relation between size and a structure of a population on the one hand, biological change on the other, as well as the nature and relation of genetic and nongenetic factors in man's adaptation to his environment.

Thus physical anthropology, which studies variation in man, would in future rest on:—

I. Judicious physical measurements and observations
II. Study of genetics

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* The word Ecology used by Haeckel for the environmental studies, carries an idea, which is expressed in Sanskrit literature by words like "divaukas", "jalaukas" meaning residents of heaven and residents of water. The root in these sanskrit words "okas=house" is nearly the same as the root in ecology which is "oikos=house (Greek)".

III. Population studies or Demography
IV. Environmental studies or Human Ecology.

Three types of research in physical anthropology can be distinguished.

1. Studies whose goal is addition to the general body of knowledge.
2. Next, comes the intermediate area, where studies border on, and are related to the practice of medicine.
3. The studies primarily meant for practical purposes like trade, etc.

Researches in the intermediate area are more intimate to the man himself. During the past few years, and as a result of having gained unusual experiences in world wars, Medical world is busy changing its old concepts, and reorienting its approaches to man's health. It is seriously thinking that anthropology is its need of the hour. Let us see, therefore, as to how anthropology will help medicine.

3. THE POSITIVE USEFULNESS OF NEW ANTHROPOLOGY TO REORIENT THE HEALTH ORGANIZATIONS AND CONCEPTS OF DISEASE

It has been observed that anthropological knowledge, if used knowingly and with planning, would be useful in two directions.

3.1. First direction would be toward the improvement of organizations in medicine.
3.2. Second direction would be toward understanding disease itself.

3.1 Organizations in medicine would improve and be more efficient, if social aspects about these are correctly understood. The various considerations, required to be done would be as follows:—

3. .1. The place of medicine in the structure of society.
3. .2. Cultural knowledge necessary for running the health centres efficiently.
3. .3. Social relationship between a patient and a physician.
3. .4. Social sanctions for sickness.
3. ..5. Medical treatment as a social control.
3. .6. Adoption of modern medical care has to be done carefully, and thoughtfully, if good results are desired.
3. .7. Medicine as a social group.
3. .8. Hospitals as social systems.
3. .9. Wards as social groups of patients.

3.1.1. The place of medicine in the structure of society has long occupied medical historians and increasingly has become a conscious problem for medicine. Stimulated by this interest, social scientists in U.S.A. have come to examine—

1. Medicine as a part of the social systems.
2. Community attitudes towards health, illness, and medical practice.
3. The professional roles associated with medicine.
4. Social structure of the hospitals.
5. The interaction of patients on various kinds of wards and its effects on their progress in treatment.

3.1.2. Foster points to the types of cultural knowledge that a technical aid administrator should have in order to plan the work of health centre effectively.

1. *Knowledge of folk medicine.*
2. Extent of literacy.
3. Family social organization.

4. Value systems.
5. Local costs of living.
6. Local political organizations.

Further, it is essential to know:—

7. Local theories of disease and its treatment.
8. Relationship of the local people to the modern-trained medical people in that area.
9. Food production and consumption.
10. Controlled culture changes, before and after health programmes at intervals.

3.1.3. In any health or medical care programme, much depends on patient-physician (Social) relationship. Waterson says, "the relationship between the doctor and his patient does not exist in vacuum. . . . . We have not yet given sufficient attention to the sciences that deal with this aspect of human relations." Both the sick and the physician have a distinct social role, one of the sick sanctioned by the society, and that of the physician developed by his training. Both the sick and the physician have their privileges.

Social role (sick)	Social role (physician)
1. Exempted from doing some of his normal social obligations.	1. Place the welfare of the patient foremost and grant his essential unconditional support.
2. Not held normally responsible for being ill.	2. Assume explicit or implicit control of the sanctions in many areas of the patient's life.
3. Defined as being in need of help.	3. Have access to physical and mental intimacies of the patient not ordinarily revealed in normal relationships.
Obligated, by the contingent legitimation of the sick role, to try to get well as quickly as possible.	4. Be barred from taking advantage of, or reciprocally participating in such intimacies.

3.1.4. Social sanction for sickness:—Social sanction for a sick role varies according to the societies. In individual families an arbitrary decision for sanctioning the sick role may be taken, or may be denied in some circumstances. Even the notion of disease itself depends on the decisions of the society, primitive or sometimes cultured, rather than on objective facts. It is then possible, nay sometimes is observed, in a society's history, to die of a disease, without ever being sanctioned as sick by the society itself.

3.1.5. Medical treatment as a social control:—It is true that all medical care, and particularly Psychotherapy is a process which helps an individual in treatment, but it can also be considered, in a wider sense, a form of social control.

3.1.6. Adoption of modern medical care has to be done carefully, and thoughtfully, if good results are desired. If it is true that cultural changes occur with least conflict and confusion along lines of established community patterns, then research in each community should centre around the investigation of the social processes which occur when any health programmes are started. With the national health schemes undertaken by different Indian States, this aspect of investigation should not be lost sight of, if good results are desired. It would not be useful to depend on propaganda, that the modern health programmes are the best, and sorcery, magic spells, prayers, manual rites, ritual dances etc. are all nonsense. Hsu (1943) observes, "if we follow the thought and ways of culture as expressed through the bearers of culture, Magic and Real knowledge, are not only intertwined, but may even be undistinguished, so that, for reaching one and the same end, the individual oscillates between one and the other: or resorts to both simultaneously, with the greatest facility and ease of mind."

The tendency of doctors, and nurses to ignore, if not to ridicule, folk concepts of illness probably strengthens the popular belief that certain categories of illness are not understood and cannot be treated by modern medical men.

3.1.7. Medicine as a social group:—Medicine is not only a professional but a social group, in which work is carried on within the framework of an elaborate social machinery rather than in a freely competitive milieu. There are cultural and social aspects of gaining admission to a medical or āyurvedic college (both being separate social groups), getting housemanship jobs, acquiring practice, and developing informal relations with colleagues.

In our country, the nursing profession has not reached the level reached in Europe or U.S.A., still the nurse in India has all the defects of her sister in Western countries. She is caught between writing notes, swabbing throats, and injecting patients. She has neither the time nor the opportunity, to dispense the emotional gratification to the patients. Moreover, such emotional support as she is able to give, is all too often viewed by the nurse herself and by the hospital system as ancillary to her profession and almost unprofessional. Authoritarianism is nearly a rule in nursing schools, and one smells of convent from which nursing has come.

Much of the dissatisfaction expressed by nurses may stem from the lack of an opportunity to replenish and satisfy their own emotional needs.

3.1.8. Hospitals as social systems:—The ratio of modern hospitals to the population in India is very low in comparison with other progressive countries. But those which we have and are having are developing with the defects also inherent in the type of organization. Smith (1949) found that the hospitals show, to a far greater degree than industrial concerns, high interpersonal tensions, bitter conflicts between departments, and an amorphous structure which lacked defined roles and areas of authority and responsibility.

All the basic substructure of a hospital (medical staff, nurses, patients, special services such as pathological laboratory, X-ray, pharmacy, etc.) are subject to a dual control—one is the acknowledged formal administrative line of authority, the other is the more informal but very potent power of the doctor. Tensions existing between members of these authority systems are often chronic and extreme. The pathologist complains; "My girls in the laboratory have one trouble, every doctor in the hospital is their boss."

A significant difference is pointed out between industries and hospitals: In the industries the actual production work is done by workers at the bottom of authority hierarchy; in hospitals the production workers (the doctors) have high prestige.

A hospital is a system of discrete and mobility-blocked levels within which the consciousness of the status is at a maximum. Unlike almost any other organization for work in the society, a hospital permits of little upward movement, no service worker can become a technician, no technician can become a nurse, and no nurse can become a doctor. If any individual wishes to change his occupational class, he must leave the system for a long period of outside training before returning at a higher level. Such a structure makes for the development of quite different value systems on various levels, and inter-personal relationships between levels are highly formalised. All this has an important effect on the nature and flow of communications through the system. Such a rigid hierarchical structure is neither administratively the most efficient, nor therapeutically the most efficient setting for patients suffering from difficulties, in getting along with their fellowmen. The need for collaboration research between medicine and on other types of environmental settings more conducive to the successful treatment of physical and mental illness has to be realized.

3.1.9: Wards as social groups of patients:—Patients in a ward are not the aggregate of individuals but a social group, and hence their therapeutic progress may be directly influenced by—

1. The nature and the extent of their interpersonal relations with other patients and with staff members;
2. Moreover their observable behaviour, which is a datum of significance for any illness in any hospital, is related, not only to factors in their illness but also to the influence of the situation upon their action.

3.2. Anthropology in understanding disease itself, is becoming of prime importance. The recent interest shown by physicians in the psychological and social concomitants of disease seems to be the resultant of the broad trends,

1. the apparent great increase in the incidence of chronic physical and mental illness in the civilized world,
2. Reawakened interest in the multiple stress and multicausal aspects of all types of disease.

If the collaboration between anthropology and medicine is to prove truly fruitful, it will be probably in this rich unworked area.

Parrot (1945) has pointed out that in U.S.A. 25 millions have some chronic disease and 1 million deaths, and 1,000 million days of disability can be attributed to chronic disease. The leading diseases are Rheumatism, Heart disease, Diseases of the Circulatory System, and Allergic diseases. The increasing control of communicable disease, the progressive reduction in infant mortality, and all round increase in life expectancy have probably brought about a shift in the distribution of age and illness within the population. It looks that mortality would be replaced by morbidity. Increased chronic and mental illness may constitute a diversion of tendencies to deviation from other channels of expression, into the role of illness.

Boas (1910) observes that "consideration of man as a domesticated animal is also of great importance—if some hunting tribes are excepted—for a clear understanding of his mental processes. We might perhaps say that the range of mentality of the domsticated forms seems to be, on the whole, wider, and this condition increases with increasing degrees of domestication."

In relation to anthropology the problem of psychosomatics falls within the special field "personality and culture", which is the study of relation between cultural environment and personality formation. Personality and culture, however, is a new area of study, and in any country a negligible number of anthropologists are engaged in it. Anthropologists should expand their horizons and undertake the cross-cultural studies of psychosomatics. Such studies might be undertaken for the purpose of investigation of the relationship between the cultural factors and psychosomatic illness.

1. Incidence of behaviour disorder and psychosomatic illness, among neighbouring tribes differing in culture and in type, and frequency of disorder might be studied and compared.
2. Where parts of tribe are undergoing acculturation by tribal centres of welfare in India, while other parts of the tribes are relatively untouched, the accultured could be compared with non-accultured.
3. In the culture of India there are many subcultures, influenced by religion, caste, profession etc. Though some of these have been the objects of study, these studies were purely social, or physical, or socio-physical. With the new angle of personality and culture new reoriented studies will have to be planned by a group of scientists belonging to different disciplines.

NEW DEFINITION OF CULTURE

Jules Henry, has stressed the need of reviewing the traditional concepts. If the group of scientists of different disciplines have to work together, with a common aim, it is necessary to make the exchange of ideas easier. Outstanding among the concepts, is the concept of "Culture", around which the future research is to revolve. Concept of culture must be understandable to sociologists, cultural anthropologists, psychiatrists, morphologists, biochemists, physicians and others,—to name the scientists of different disciplines who will have to work in close harmony together. Jules Henry defines "Culture" as "THE INDIVIDUAL'S OR GROUP'S ACQUIRED RESPONSE SYSTEMS." It makes clear in simple definition, that when we study the organism and its patterns of physiologic functions, we have to take into consideration response systems that are determined not only by hereditary processes, but also by events in the external world, since it is the event in the external world that determines the acquired response system. The definition of culture in terms of acquired characteristics, leads us back to Boas' original conception of changes in mental function under the influence of domestication It is the domestication of Homo Sapiens that brings it about, that man has an enormous number of response systems that are not genetically determined.

Conception of culture as response systems acquired through the process of domestication places the socalled psychosomatic disorder within the general process of evolution of the species. These disorders then appear as part of the larger design of the "natural order" and take on a new meaning. One might as well hypothecate that what appears in the clinic as visible dysfunction might be just one of an enormous number of imperceptible changes which are taking place at the same time, but which cause no discomfort. This meaning is simply that culture as an instrument for survival, generates new selective processes through the creation of new response systems. Who shall survive, will be determined in part by these selective processes. This argument is an answer, if an anthropologist were to deny psychology a place within the theoretical framework of cultural anthropology. The development of the science of Psychosomatics, the undeniable relationship between mental life and bodily function and survival, place social psychology within the general purview of anthropological research.

Since the human animal has become enormously dependent on acquired response systems, his psychic integration is subject to whatever conditions exist in the "domesticating environment". The more numerous, the more varied, and the more conflicting the response systems the organism is forced to acquire, the more the organism is subject to psychic malfunction. This is what makes it possible to produce neurosis in lower animals also: we force to acquire response systems that are too complicated or too conflicting for their simple organization (demestication of wild animals). The need to develop response systems in excess of one's capacity to do so also, produces behaviour disorder in man. The conception of the response systems acquired through domestication gives sense to the notion of the enormously taxing character of the complicated and contradictory "Western Culture".

Thus it can be seen that from the anthropological standpoint of view, psychosomatics may be considered as an aspect of the study of response systems acquired by Homo Sapiens during domestication. In the contemporary anthropology, psychosomatics would fall in the field of "personality and culture", the new subject of anthropologic research and investigation.

Anthropologic, medical, and biochemical research among primitive tribes would give additional, and needed insight when carried in large populations and where other conditions make good experimental design possible. It is left to be seen whether Indian scientists would undertake such research in India, where there is a rich field for this type of research.

After consideration of the new definition of culture, it would not be out of place here, to give some thought to the changing concepts of disease.

CHANGING CONCEPTS OF DISEASE

Modern Medicine has developed on a structural basis, a concept originated by Virchow. This structural concept of disease led to the separation of illness from psyche, and disease came to be thought of, as only a disorder of organs and cells. The structural concept, being the basis of thought, naturally developed in thinking in the terms of systemic diseases. With systemic diseases came the specialists to treat these diseases, and with the specialists came the introduction of instruments of precision and the mechanisation of medicine began. Medicine now contented itself with the study of the organism as a group of different systems and as a physiological mechanism, and got impressed by blood chemistry, electrocardiography and other methods of investigation, but unimpressed by, and, indeed, often holding in contempt the psychological background of the patient which was not considered so scientific as the results of the "laboratory studies". This period may, in truth, be referred to as the "Machine Age in Medicine". It is not to be denied, however, that remarkable developments have occurred during the "Laboratory ascendency" but it must also be admitted that the emotional side of illness had been almost entirely neglected. ...

Nineteenth Century concept of disease would be that, cellular disease was followed by structural alteration which led to physiological or functional disturbance.

In the twentieth century this formula underwent a change. For example, in Essential Hypertension and vascular disease the formula was altered to read that functional disturbance was followed by cellular disease which led to structural alteration.

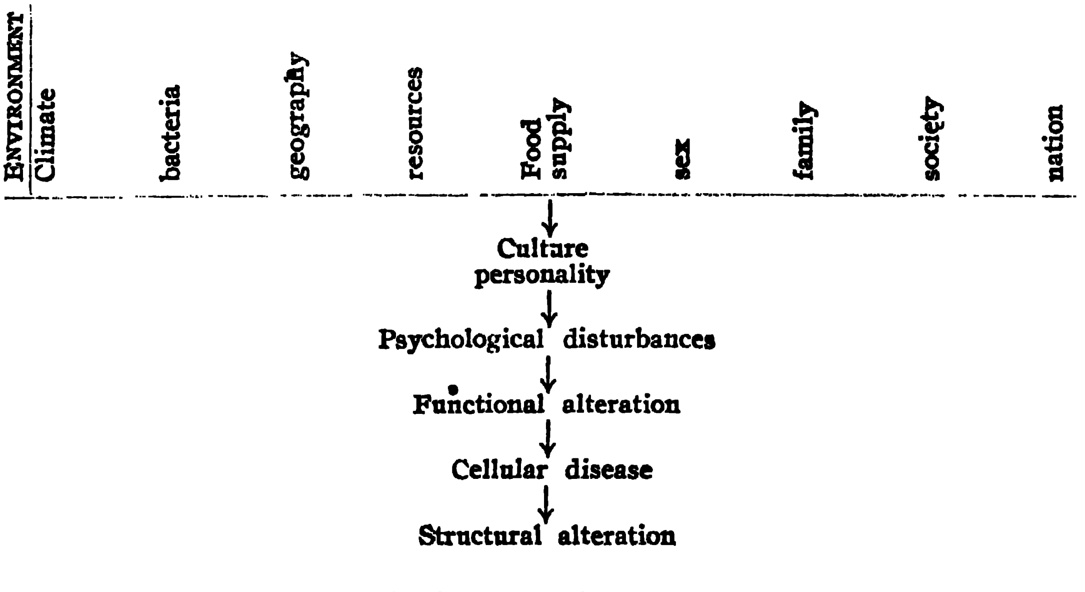
We are still in the dark as to what may precede the functional disturbances. It is quite likely that further investigations may permit us to say that Psychological disturbances may precede the functional disturbances.

Psychological disturbances in turn are the effects of environment on personality and culture (with its new definition in mind), which initiate the psychological disturbances.

The concepts of disease changing from time to time are represented thus:—

Virchow's 19th century structural concept		*20th century change: essential hypertension, vascular disease*
Cellular disease	1	Functional disturbance
↓		↓
Structural alteration	2	Cellular disease
↓		↓
Physiological or functional disturbances	3	Structural alteration

HYPOTHETICAL FURTHER POSSIBILITY OF CHANGE IN THE CONCEPT OF DISEASE



In ancient medicine, the humoral theory prevailed claiming the fluids of the body to be the carriers of disease. In ancient Indian Medicine, Caraka and Suśruta say, "Therefore a patient should be examined from the following points of view: prakṛti (vāta, pitta, kafa), caste influences, lineage of family, regional influences, weather influences, subjective urges, complexion, voice, malconditions, essences or dominances, body build, body proportions, likes and dislikes, mind power, capacity for physical work, eating and digesting capacity, old age influences." 1·1). Nothing can beat, so far, the considerations about a picture of a patient in his totality as presented by Caraka and Suśruta.

Great political upheavals caused by too frequent aggressions on India, hampered organized thought and scientific progress in India. Since the seventeenth century, impacts with streamlined Dutch, Portuguese, French, and English, became urgent, and helped to demolish whatever was left of Caraka and Suśruta, and to create an admiration for the medicine brought by these foreigners. In Europe, its Ancient Medicine was demolished by different events. The Western thought in medicine underwent a great upheaval during the Renaissance. During this period, a method of investigating a cause of disease in the body of a patient by dissecting it after his death developed. "Morgagni, in the middle of the eighteenth century, claimed that the seat of various diseases was in particular organs such as the heart, kidney, liver, etc. "With the introduction of the microscope, the localization of the disease became even more confined, the cell became the seat of disease. It was Virchow, to whom pathology owes so much, who declared that there are no general diseases, only diseases of organs and cells. His great achievements in pathology and his authority established a dogma in cellular pathology, which has influenced medical thinking up to the present day. Virchow's influence upon etiological thought is the classical example of the historical paradox that the greatest accomplishments of the past become the greatest obstacles to further development. The observation of histological changes in diseased organs made possible by the microscope and by the refined techniques of staining tissues determined the pattern for etiological thought. Search of the cause of disease long remained limited to the search for local morphological changes in tissues. The concept that such local anatomical changes may result from more general disturbances which develop in consequence of faulty function, excessive stress, or even emotional factors remained to be discovered much later. The less particularistic humoral theory, which came to be discredited when Virchow defeated its last representative, Rokitansky, had to wait for its revival in the form of modern endocrinology." Stefan Zweig, a non-medical man, in his book 'Mental Healers' says: "Disease meant now no longer what happens to the whole man, but what happens to his organs. . . . And so the natural and original mission of the physician, the approach to disease as a whole, changes into the smaller task of localizing the ailment and identifying it and ascribing it to an already specified group of diseases. . . . . . This unavoidable objectification and technicalization of therapy in the nineteenth century came to an extreme excess, because between the physician and patient became interpolated a third entirely mechanical thing, the apparatus. The penetrating, creative synthesizing grasp of the born physician became less and less necessary for diagnosis."

It required two great world wars to revive the interest of the physician in the totality of a patient. During these wars, practically all the population of nations turned into active fighters and/or defenders. Soldiers went to camp and fight, torn away from their homes and countries, in far distant lands. They suffered not only from the wounds caused by weapons, but by the effects of strange circumstances in which they were required to remain for very long periods under mental stressses and strains. Medical science had to investigate and strive hard to keep them fit, and to refit them if maimed either in body or mind, because these wars required huge numbers of able bodied men, and the supply of personnel was limited. Conditions required for blood transfusions, and attempts at understanding other hereditary ailments gave birth to modern genetics (1·2.). Gene and the concept of heredity got linked. Various pathological diseases were known to be hereditary, and a gene became their carrier. The original concept of disease began to be looked upon with suspicion. The return to the ancient approach to disease and consideration of a patient in his totality, began, because hereditary effects, influence not only the whole physical structure of the body, but also organism's function and behaviour. Function and behaviour of an individual form the basis on which the edifice of social science is built.

Alan Gregg makes the following impressive statement:

"The totality that is a human being has been divided for study into parts and systems ; one cannot decry the method but one is not obliged to remain satisfied with its results alone. What brings and keeps our several organs and numerous functions in harmony and federation? And what has medicine to say of the facile separation of "mind" from "Body"? What makes an INDIVIDUAL, what the word implies—not divided? The need for more knowledge here is of an excruciating obviousness. But more than mere need there is a foreshadowing of changes to come. Psychiatry is astir, neurophysiology is crescent, neurosurgery flourishes, and a star still hangs over the cradle of endocrinology. . . . Contributions from other fields are to seek from psychology, CULTURAL ANTHROPOLOGY, SOCIOLOGY, and philosophy as well as from chemistry and physics and internal medicine to resolve the dichotomy of mind and body left us by Descartes."

Let us help in bringing out these prophetic changes by intergrating all aspects of ANTHROPOLOGY with MEDICINE.

Let us further hope that the future man lives in happiness, by developing harmony with each other, with all his differences in body and mind.

Lastly, I thank you for having given me an opportunity to express my views, by electing me the President of Anthropology and Archeology Section at the 1958 Session of Indian Science Congress Association.

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SECTION OF MEDICAL AND VETERINARY SCIENCES

President :—Dr. A. K. Bose, M.Sc., M.B. (Cal.),
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PRESIDENTIAL ADDRESS

SOME PROBLEMS OF HEART DISEASE IN INDIA

When a man dies the heart naturally will have failed, but that is not to say the man died of heart disease or heart failure. This misconception about heart failure as well as non-recognition of actual heart disease has considerably vitiated the statistics in our country, yet it has been accepted by all that the incidence of and mortality from heart disease in India are as great as in other countries. The basic scientific problems with minor modifications are also fundamentally the same all over the world.

The main heart diseases which have so far baffled the investigators in determining their basic nature are coronary heart disease hypertensive heart disease and rheumatic heart disease. It is recognised by all, in all countries, that heart disease particularly coronary heart disease and hypertension is a major killer. Along with these, rheumatic heart disease, though the end through it is not as dramatic as in the other two, is responsible for 95% of heart disease in childhood and for more than ¼th of heart disease seen in adults in India. Apart from these, three conditions, it is also necessary to discuss congenital heart disease, though from a different angle, nevertheless, constituting an unhappy position as far as our country is concerned.

Coronary Arterial Diseases:

This is due mainly to atherosclerosis of the coronary arteries, producing the clinical conditions of angina pectories, coronary insufficiency and coronary thrombosis. What is most disturbing is to realise the fact that good deal of atherosclerosis may develop without producing any clinical symptoms, with the result, we have, to-day no definite means of knowing whether or not and to what degree the coronary arteries are involved in symptomless cases. If we are to succeed in knowing the position the problem is to be tackled from the point of view of the factors that produce atherosclerosis. Here again we are far from possessing any definite knowledge of the process. During recent years a good deal of experimental, biochemical, biophysical and clinical work have been carried out by various investigators to try to unfold the mystery of formation of atherosclerosis.

It has been known that abnormal amount of cholesterol is deposited in the wall of the coronary arteries in producing atherosclerosis. Though not unanimous in their results, investigators are generally of the opinion that such cases are associated with hypercholesterolemia. The source of this hypercholesterolemia again is not definitely known but is thought to be both exogenous and endogenous. It has also been noted that by feeding human beings with excess of cholesterol hypercholesterolemia can not be producd to any significant degree. Even if the source of arterial cholesterol is the cholesterol in blood, in the form of lipoproteins, the important point is to know how does the plasma cholesterol enter into the wall of the arteries. The present conception is that various factors, in combinations, are responsible for the process. It was found that it is not cholesterol but cholesterol phospholipid ratio that was more important in causing disequilibrium in the physiochemical property of the blood plasma in the unlinking of the cholesterol part of the lipoproteins and its precipitation and subsequent imbibation into the intima of tne vessels. It has also been found out that larger molecules of the lipoproteins, the chylomicrons are perhaps more important in this respect. Electrophoresis of blood plasma and by the more simple and economic method of paper chromatography it has been noted that increased proportion of β lipoproteins are generally associated with atherosclerosis of the coronary arteries and is even found normally in man, by contrast in species relatively resistant to atherosclerosis.

More recently the plasma lipoproteins have been differentiated by the ultracentrifuge, in which the strong gravitational force floats the large protein molecules to the surface at velocities related to their molecular weight and specific gravity of the solution.

By studying the flotation of plasma lipoprotoins in the ultracentrifuge, Gofman and associates found that patients with clinical atherosclerosis have a high concentration of Sf 12-20 lipoproteins much more often than normal individuals.

Low cholesterol and low fat diet and injection of heparin, which are thought to influence atherosclerosis favourably, also altered the lipoprotein pattern towards normal, as determined by this ultracentrifuge method. It has even been claimed that it was possible to predict the future possibility of and past incidence of atherosclerosis by this method. This however has not been confirmed by others.

If that is the position about lipoprotein, the mechanical condition of lateral pressure exerted by the column of blood seems to be equally important and this fact accounts for the association of atherosclerosis with either systemic or local hypertension. Question, however, arises why then the atherosclerosis is often restricted to coronary or/and cerebral arteries.

Though the biochemical factors of blood plasma is being investigated intensively and extensively, there has been no serious attempt to go into this question of primary arterial reaction including its metabolism. It seems a detailed study about the metabolism of the arteries and its physical configuration will throw considerable light on the production of zonal atherosclerosis.

Other factors also interest etiology of atherosclerosis, they are the questions of hormones, heredity and ageing.

It is a significant fact that women suffer from coronary atherosclerosis much less than men except when there are such diseases as diabetes mellitus, nephrosis, hypothyroidism etc. It has also been noted that stilboestrol administered for a long time in cases of prostatic carcinoma would render the blood lipoprotein patterns to non-atherogenic level.

Normal young women, in whom coronary occlusion is rare, have a relatively smaller amount of lipoprotein than normal young men ; likewise the "atherogenic" lipoproteins of the Sf 10-100 classes in the ultracentrifuge is found in relatively less amount in normal young women than in normal youngmen. Bilaterally oophorectomised women show relatively increased severity of atherosclerosis than in normal of the same age group of the same sex. Thyroid relation of atherosclerosis has already been noted. Thyroid administration inhibits experimental atherosclerosis in cholesterol fed rabbit or chick. It is well known that myxoedema is associated with hypercholesterolemia and atherosclerosis.

Cushing syndrome, due to excessive adrenocortical hormone is frequently associated with hypercholesterolemia. But neither cortisone nor corticotropin has favoured experimental cholesterol atherogenesis.

Presence of higher blood pressure, no matter how produced, is in favour of aggravating the process of atheromatosis.

Study of cholesterol in diet therefore assumes importance in formulating our idea of atherosclerosis.

Some have stated that atherosclerosis is an inevitable consequence of aging and therefore an irreversible process. It has some justification in a general way, but frequently the condition is found in a very minimal degree in cases of very old people and advanced atheroma is found in young people. Ageing therefore fails to explain the difference. We should therefore discard this fatalistic approach to the problem of atherosclerosis and consider the condition as, at least, partially amenable to prevention.

Cholesterol is found in fats of animal origin and not in vegitable fat. In man again there is little correlation between blood cholesterol and cholesterol in the diet over a wide range of ingestion. Serum cholesterol is reduced only after very low fat and almost no cholesterol as in Kempners rice diet. It has been noted again that only highly unsaturated fats may produce a significant lowering of blood cholesterol. Therefore the type of vegetable fat is important in the production of blood cholesterol level in human subjects. In a recent study the serum cholesterol was found to be significantly lower in the group on a low fat diet than a control group with relatively liberal fat diet, though the lipoprotein levels did not differ very much. It appears, therefore, that the diet fat and its nature and not merely the cholesterol in it that determines the blood cholesterol level.

More recently evidences have been presented to suggest that the proportion of unsaturated fat, particularly the fatty acid content of the diet to the total quantity of fat in the diet that is responsible for the concentration of cholesterol in the plasma and hydrogenated vegitable fat raised serum cholesterol.

In China, where fat, particularly animal fat is considerably omitted in the diet, coronary arterial disease is rare, though hypertension is not infrequent. The Bantus of Capetown obtain 16% of calories from fat, the Negroes 25% and local Europeans above 40%. Severe atherosclerosis is rare amongst the Bantus, fairly frequent amongst Negroes and very common among the local Europeans.

Aschoff reported a drop in atherosclerosis amongst the Germans after the World War I, when dietary fat was considerably reduced.

In persons with hypercholesterolemia, in order to prevent the absorption of even small quantities of cholesterol, total quantity of fat in the diet must be greatly reduced. Vegetable fat containing long chain fatty acid which forms esters with cholesterol and which are poorly absorbed can be used instead of animal fat.

There are also some evidences to show that such substances as choline, inositol and pyridoxine act to mobilise cholesterol and other lipids from the liver by decholesterolising tissue depots.

It has been observed that heavy physical exercise will keep down the lipoproteinemia in the same subject but others have found opposite results. Though statistically serum cholesterol and low density lipoproteins as detected by Gofman method in using the ultracentrifuge are significant in its association with clinical coronary thrombosis, they have no specific predictive value in any one individual.

The question of diet is therefore naturally, very important in the prevention of coronary and cerebral arterial disease, but unfortunately on the basis of clinical and experimental findings it is not possible, to-day, to state that a drastic reduction of fat in the menu would definitely prevent atherosclerosis. In the experimental atherosclerosis, however, diet is certainly an important factor, yet actual thrombosis and infarction have not been clearly produced experimentally. It can only be stated in the general way that high fat consumption is associated with atherosclerosis, but it is not possible to make the idea exclusive of such other conditions as caloric balance, changes in body weight and other metabolic and dietary factor including proteins. Diets providing 15 to 20% of caloric from fat is considered safe and is capable of providing a palatable menu. In individuals with family history of early deaths from atheromatus conditions special diets have to be provided, the exact nature of which is still undefined. Only continued work on dietatics on statistically controlled group of population with different quality and quantity of diet along with fundamental research can give the nation a menu that will reduce the incidence of atheroma and consequent stroke and coronary thrombosis to a very considerable extent.

In our country the population is spontaneously divided into such varied dietatic group as are of great help in the planning of such experiments with human material. In a general way fat and cholesteral have been given special significance, but experiments show that proteins, carbohydrate, choline, pyridoxine and organic sulphur also have been implicated in atherogenesis.

Present Position: Atherosclerosis, cerebral thrombosis and myocardial infarction depend on various factors, some of which are controllable such as the diet and nutrition, particularly high fat content of food and specially of its unsaturation. Caloric balance, exercise and body weight are equally important factors. The, so far, apparently uncontrollable and partially controllable factors are the question of sex, heredity and hormonic imbalance. It can not therefore be stated that simply a drastic reduction of fat in the population will reduce the incidence of atherogenesis considerably. What is applicable as a national dietary principle with regard to atherosclerosis must however be modified while an individual with clinical atheroma is being followed up.

Our country with various types of population with definite but different dietary habits provides a unique ground for investigation into this matter. The cardiologist, the biochemist, the biophysicist, the nutritionists and the biostatistitian should combine together to find out this etiological aspect on the basis of a "pool" research programme.

Hypertension: It is well known that there are various etiological types of the condition and essential hypertension is the one in which no definite etiological factor is detected. But it seems likely that the condition known as essential hypertension is not one disease but a group, having predominantly different etiology, though the gross clinical manifestations may appear same at the recognisable stage.

For persistent hypertension spasm of the arteriols is a primary factor, but what condition brings on this spasm is not definitely known. Endocrine imbalance, particularly affecting the adrenals is one such condition as in phoeochromocytoma. In pheochromocytoma there is an increased amount of circulatory epinephrin causing arteriolar constriction. In case of brain tumour, the increased intra craneal pressure stimulates the vasomotor centre. Presence of adrenal cortical steroids in the placenta in toxemia of pregnancy points towards the same direction. Cushing syndrome is a classical example of the same type. But these do not explain the condition in the vast majority of cases. Clinical hypertension was regarded in some way related to the kidney condition from the days of Bright, until Goldblatt in his classical experiment of clamping the renal artery in dogs produced something akin to hypertension in human being.

Again it has not been possible to demonstrate increased quantities of renin or hypertensin in the blood in essential hypertension as was postulated as the cause by Goldblatt. Further complication has been added by the recent experimental fact that bilateral nephrectomy in dogs, life being maintained by an electrolyte free diet and the use of an artificial mechanical kidney, hypertension instead of hypotension develops.

Yet it should be realised that no demonstrable change of renal function at the early stage of the condition does not rule out the more subtle changes in renal physiology that may be pathogenetic. The possibility of such a state is suggested by the presence in essential hypertension of an increased plasma concentration of vasoexcitatory material (VEM) produced by the kidney. These are not found in the normotensives but are also found in experimental renal hypertension produced by the Goldblatt method in dogs.

It has also been shown recently that hypertension could be maintained by the intravenous infusion of rabbit renin into the rabbit on an amount that produced an increase in plasma renin concentration not detectable by present methods of assay. The renin content of hypertensive plasma should therefore be reassayed with a larger quantity of blood. Antirenin to hog renin has been found antihypertensive to dogs with experimental renal hypertension, but it has no action on human renin. If we could produce antirenin to human renin we shall have at least found out what percentage, if any, of patients with essential hypertension have their hypertension on a renal, renin basis.

Evidences of neurogenic conception of essential hypertension are mainly circumstantial and includes the antihypertensive effects of tranquillizing and vasomotor blocking drugs in some patients. Corticohypothalamic imbalance is postulated as the mechanism, resulting finally in increased tonus of the smooth muscles of the systemic arteriols.

Experimentally hypertension has been produced in rats by strong auditary stimulation, but its patho physiology has not been properly studied. Experimentally produced "buffer-nerve" hypertension in dogs and rats by section of carotid sinus and aortic depressor nerves differ in important respects from essential hypertension and can not therefore be regarded with any conclusion at this stage.

Mild disturbance of sodium and water metabolism has been demonstrated in essential hypertension. It has been thought to be due to secretion of some as yet unidentified adrenal cortical steroid with a pronounced pressure effects. Hypertensive patients retain sodium and water more readily on sodium free diet. Clinically a group of hypertensives respond well to a salt free diet.

Recently increased aldosterone has been demonstrated in the urine of hypertensive patients. Some cases also show an increase of norepinephrine in the urine. Increased antidiuratic hormone has also been demonstrated in the urine of hypertensive patients. It will be necessary to work further on the anterior pituitary adrenal cortex function before one could say anything more definite about the endocrine electrolyte factor in the production of essential hypertension.

Heredity and body type must be operating through some type of pathophysiologic mechanism the nature of which is yet to be found out.

From the accounts given and from clinical knowledge of a large number of cases of essential hypertension regarding its different modes of therapeutic response to different types of drugs, tempo, progress and difference in the combination of symptom complex, it appears reasonable to think that essential hypertension is a generic classification consisting of several clinical types.

Here is a great field for standardising the types by statistical analysis through "pool" research on a nation-wide scale. This will at least clarify therapeutic procedure if not advance fundamental research in the line.

Congenital Heart Disease: Incidence of congenital heart disease has been generally estimated to be about 4% of all heart cases, though it must be stated that diagnosis made on clinical grounds only is likely to be incorrect in a good few.

We do not know much about prevention of the condition and it is not likely that we shall be able to know about it in the near future. Cardiovascular surgery has, however, considerably changed the outlook in a large percentage of congenital heart condition. The most important problem of congenital heart disease to-day in India is to provide proper surgical facilities which will cure many selected cases. This requires exact diagnosis, which involve highly technical team work and expert surgical help. In this respect the diagnostic and operative side cannot and should not be made exclusive, one must take part on the other's work. Above all, the pre-operative and post-operative anaesthetic and nursing care should form a very important part of the organisation. The general practitioner from whom the cases are referred should take up an intelligent informative role about the whole procedure and help follow up of the patient by the expert team.

Every step in the process involves highly technical methodology and can be performed only on an institutional team work.

The problem of congenital heart diseases, therefore, today is the establishment of such medico-surgical centres where the cardiologist, anaesthetist, radiologist, biochemist, surgeon, the special nursing staff and the general practitioner would continue to form a team to give relief to such patients.

In this connection, it is useful to mention that the Cardiological Society of India, Indian Council of Medical Research and various State Governments with their technical personnel can sit together and formulate an appropriate scheme for the establishment of such regional centres. When this is done, investigation into the other basic conditions associated with congenital heart disease can be taken up by the team with the help of embryologists, histologists, biochemists and others. Here is a subject where management for therapeutic relief should precede investigation regarding prevention at least for many years to come. The appropriate department of the Government must take up the initiative in the matter.

It would be a social crime if children with congenital heart diseases, that are amenable to surgery are allowed to continue a poor, precarious and passive existence for no fault of their own or of their parents. Where there is a remedy for a disease it should be made available to the diseased.

The Nature of Rheumatic condition : Rheumatic heart disease is very common in India and so are its consequences. We, physicians and surgeons in general have been mostly dealing with the consequences of not only hypertension and atheroma but also of rheumatic infection, but a time has come, in fact it came long ago, when we should have taken more interest in the factors that produced these conditions, if we were to stop the consequences.

Rheumatic fever, the cause of rheumatic heart disease is considered to be an allergic manifestation of a previous streptococcal infection and pathologically it produces what is known as Aschoff body ; the exact histology of which will vary depending on the structure of the body involved, whether it is the heart, joint, lung or brain substance.

From this point one proceeds forward to the formation of rheumatic heart diseases with clinicopathological exactness but the tracing of the condition backward is enveloped under equivocal findings and indefinite circumstances, yet out of the bizzare collection of evidences a set pattern is evolving out to give us a better picture of the position.

Belief in the infective nature is based on, outbreak of epidemics, comparatively high familial association, similarity of seasonal occurrence with other known infections and importantly on clinical, pathologic, bacteriologic and immunological considerations.

It has been found that about 90% of patients suffering from acute rheumatic fever have considerably increased quantity of anti-streptolysin "O" in their serum. This would certainly indicate a close relationship with acute rheumatic fever and streptococcal infection belonging to Group "A". It has been suggested that excessive antibody production may be related to the non-suppurative condition of the rheumatic manifestations. The absence of antistreptolysin in some cases may be due to failure of some of the Group "A" to elaborate antistreptolysin "O". Presence of antifibrinolysin in large numbers in the serum both in acute rheumatic infection and known haemolytic streptocococcal infections is suggestive of the allied nature of the condition.

The concept that rheumatic fever can persist in the absence of viable streptococci arose from clinical observations and has been widely held by workers in this field. In any event, there are clinical observations that are difficult to reconcile with the concept that presence of viable streptocci is necessary for the continuation of active rheumatic process. This makes the position of prophylactic antibiotic therapy uncertain. This concept is supported by the apparent failure of penicillin therapy to affect the course of the disease. It is also well established that penicillin is effective only at the growing stage of streptococci and they may remain viable when growth and metabolism have stopped and then require much larger concentration of penicillin which so far has not been extensively tried. It is necessary to come to a definite knowledge about this fundamental point.

Klempnar and his colleagues were interested in the condition—disseminated lupus erythematosis and published and article "Diffuse Collagen Disease", in which they pointed out that in scleroderma and disseminated lupus erythematosis, there were conspicuous and systemic alterations in the extra cellular components of the connective tissue and that from the point of morphogenesis, they might be regarded as disorders of the connective tissue system.

Thus the useful but limited concept of cellular pathology was broadened to take account of a chemical pathology affecting primarily, not the cells but the ground substance of this connective tissue. This connective tissue is an organ and can have disease entities primarily restricted to this ground substance.

It has been observed that pathologically and even therapeutically groups of diseases could be classified under the term "Collagen Diseases" with many common features. Evidences are pointing towards the fact that rheumatic fever is one member of the group with direct or indirect relations.

Studies of the structure and functions and pathology of connective tissue have been considerably helped by development of electron microscope, roentgen-ray defraction and histo-chemistry. The concept gained thereby has been put in a sounder basis by the therapeutic effect of cortisone and A.C.T.H. in these conditions.

Hyaluronic acid is a mucopoly—saccaride which exists in the skin as well as in the collagen tissue and there are evidences to show that it protects the tissue from bacterial invasion. It has also been found that some strains of group 'A' streptococci can produce the enzyme hyaluronidase, which is type specific. The enzyme by depolymerizing hyaluronic acid promotes invasion of the collagen tissue by bacterial toxins.

It has also been pointed out that the basic lesion in rheumatic fever is in the connective tissue. The possibility therefore is that an enzyme like hyaluronidase elaborated by streptococcus group 'A', causes damages by as yet unknown chemical action to the protective element of the collagen tissue with the result that the beginning of rheumatic process is established in the different parts of the human body.

However, those streptococci of group 'A' which preceds rheumatic infection, generally produces hyaluronic acid and not hyaluronidase. Thus again the mechanism of production of antihyaluronidase titre in rheumatic patients is not yet known.

Again the type of tonsillitis that is supposed to provide the streptococcus, is so common and rheumatic fever, comparatively, so uncommon, that it seems one must fall back to individual susceptibility, a very unhappy hypothesis to proceed to establish the exact actiology.

Applications of science of genetics is likely to provide further proof in this direction ; as a matter of fact recent observations tend to show that susceptibility to rheumatic fever is inherited as a single recessive character.

The value of the brilliant methods and technical skill employed in the surgical management of rheumatic heart disease can not be denied, but we look forward to the day when this method of giving relief will no longer be necessary.

We would not have cared so much for rheumatic fever if it did not affect the heart later, therefore the question of exact diagnosis at the earliest stage is extremely important.

Unfortunately there is no specific laboratory diagnostic test. The diagnosis must therefore be arbitrary and empirical. Apart from well-known clinical syndrome such minor criteria as increased P-R interval presence of C-reactive protein and evidence of preceedings β-haemolytic streptococcal infection, should be adopted particularly in equivocal cases. Recently typical histological structure suggestive of active infection has been found in auricular appendage biopsy during mitral commissurotomy, in cases regarded as non-active according to the criteria suggested, but to-day this suggested combination of criteia is all that we have to minimise both overdiagnosis and underdiagnosis of rheumatic infection.

These are the established facts and gaps towards the determination of the exact nature of acute rheumatic fever. Only experimental work, with combined efforts of all branches of medicine and the basic sciences can and will solve what is still shrouded in apparent mystery and we hope the day, when it will be done, is not far.

Physicians, particularly cardiologists, must take upon themselves the great work of finding out the detailed etiology and pathogenesis of rheumatic fever rather than be content with tackling the final form of its consequences as typically manifested in mitral stenosis.

Public Health Aspect: The frequency and importance of rheumatic fever are such, as would justify the application of a definite public health measure for the control of the condition.

Though in our country there is a definite lack of statistical account of its incidence, nobody would deny the tragic fact that rheumatic heart disease affects mainly the adolescents and when left alive it makes of him an economic handicap to himself, to his family and ultimately to the society as a whole.

Many countries in the world have already taken up a public health programme for rheumatic fever and have formulated a definite scheme for its treatment and supervision. In those countries rheumatic fever has been made a reportable disease and sufficient beds have been provided at public expense specially for such patients or in exclusive institutions.

A central integrating agency, such as the Cardiological Society of India or the Cardiovascular Sub-Committee of the Indian Council of Medical Research separately or jointly may take up the work and in a specified manner co-ordinate the work of various other organisations, or individuals, public or private.

Rheaumatic fever should be made a reportable diseases—clinical laboratory facilities, in terms of what has already been explained, should be made available for aid to the physicians for proper and early diagnosis, treatment and follow up. The co-ordinating agencies as suggested should maintain or help maintaining a register of such cases reported and supply routinely in appropriate prescribed form, instructions for treatment and follow up.

Rehabilitation programme should be developed and vocational education under expert guidance should be made available after convalescence.

It will be necessary, preferably under the direction of the Cardiological Society of India to categorise the individual patient after cure in order to get co-operation from the State and private employers for their gainful employment in suitable avocation, if necessary with less work and more pay depending on the medical status of the individual.

The problem of public health aspect must be tackled with directions of science and sympathy and no amount of stereotyped jargons of economic inability be allowed to function form any quarter whatsoever to damp this overall attempt in controlling the consequences of the disease.

The march of events tells us the glorious progress of science through the efforts of man the scientist, the architect. It must, however, be remembered that we do not yet know the exact aetiology of all these important conditions but the ultimate determination of the same, in the near future, is inevitable. We in our part must lay emphasis more on the nature than on the consequence of the diseases and be active participants in the overall programme for which research facilities need to be fostered by the state with respect to epidemiology, aetiology, clinical and laboratory features. The recent advances certainly justify great hope and optimism for the future.

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SECTION OF AGRICULTURAL SCIENCES

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PRESIDENTIAL ADDRESS

CYTOGENETICS AND CROP IMPROVEMENT

I am deeply conscious of the honour you have done me by electing me president of the section of Agricultural Sciences of the 45th Session of the Indian Science Congress. The subject of Cytogenetics, itself being the result of synthesis of two different disciplines of science namely, cytology and genetics, holds an unique position in creating, in recent years, alliances between separate and independent branches of study such as taxonomy, embryology, anatomy, cell physiology and above all, biochemistry and biophysics. Such alliances have produced, in a comparatively short period, a synthesis of ideas and a new outlook in understanding the phenomenon of evolution in general and the physical basis of variation in particular. It will not be an exaggeration to say that all biological problems have now acquired a cytogenetical aspect. Furthermore, by the application of cytogenetical methods attempt can now be made to modify characters of cultivated plants to suit human requirements with positive expectations and within a reasonable period of time.

The important rôle of genetics in human welfare and in crop improvement have been stressed upon by a few of the previous presidents of the section of Agricultural Sciences and Botany respectively (Ramiah 1941 ; Pal, 1946 and Parthasarathy, 1953). Ramanujam (1952) has in addition, reviewed the cytogenetical work done in individual crops in India within that period. In my present address I intend to focus your attention to some of the recent lines of development in cytogenetical investigations which have already shown great promise in the production of improved varieties of some of the crop plants. In this context, I would also like to touch upon those aspects of cytogenetical research which are of special interest to me and in which I and some of my associates have made some contribution. Before I deal with those, it would be necessary to mention briefly about the origin and development of this young and twin science, that is, cytogenetics.

The alliance of cytology and genetics began with the rediscovery of Mendel's laws in the year 1900 when it was shown that these laws have a material basis as indicated in the parallel behaviour of chromosomes through successive life-cycles. However, striking confirmation of the genetic principles on a material basis was found later in the work of Janssens (1909) on the chiasmata of amphaebians, which also provided the real clue to the mechanism of crossing over, and on the work of Carothers (1913, 1917, 1921) on the independent segregation of structurally heterozygous bivalents in grasshoppers. The most important and real alliance between cytology and genetics, nevertheless, came through the work of Bridges (1916-1921) on non-disjunction, deficiencies and duplications in *Drosophila* followed by his work on triploid intersexes, genic balance theory of sex-determination and on inversions and translocations. Belling (1926) in introducing the aceto-carmine technique in the study of Liliaceous plants and in *Datura*, similarly provided the basis for salivary gland investigation in *Drosophila* by Painter (1933) and in the later development of various cytological squash techniques which have proved, subsequently, so essential for making cytological observations. It is often said how different the history of genetics would have been if Morgan and Bridges could have developed the acetocarmine technique for salivary gland chromosomes twenty years earlier. In a similar way one can not over-emphasize the importance of the discovery by Muller (1927) in the use of X-rays to produce mutations of genes and in inducing structural changes of chromosomes. The first attempt, though very incomplete, to produce synthesis of principles of cytology and genetics was made by Belar (1928) in his book *Die Cytologischen Grundlagen der Vererbung*. Belar died prematurely and it remained to the genius of Darlington who attempted to formulate laws and principles of cytogenetics and thus created a real synthesis of the two subjects, Cytology and Genetics in his book, *Recent Advances in Cytology* (1932, 1937). The science of Cytogenetics, therefore, truely speaking is relatively young. Nevertheless it has a great future in the field of biology as well as in its application for the improvement of crops and domestic animals.

The origin of cultivated crop plants roughly dates not later than 10,000 years. Most of the cultivated plants have evolved due to conscious selection by man of types out of the natural variants of wild species. Improvement of crop plants have always been based, in part, on breeding from those which varied in a desired direction and most of the theories of evolution, Lamarck's as much as Darwin's, postulate that the difference between the present day species and their extinct ancestors are of the same kind as the difference between living members of a species. The immediate causes of such differences or variations (continuous as against sudden discontinuous variation) are due to segregation and recombination of characters. Therefore, traditional methods of plant breeding, i.e. selection in spontaneous population as well as selection in population produced by hybridization have led to the production of numerous improved varieties of crop plants of great economic importance. Selection alone has rendered supreme results in both self- and cross-fertilizing species (improved varieties of paddy, jute, wheat and cotton in India). Plant-breeding by means of hybridization includes two distinctly different methods ; one, utilizing the recombination and transgression in F_2 and later generations e.g. high specific yield of English wheat combined with winter-hardiness and good Kernel quality of Swedish varieties, the other exploiting the hybrid vigour of the F_1 generation e.g. high yielding corns of the U.S.A.

In recent years two additional methods acquired by the plant breeder have come to the forefront. Firstly, it has been possible to increase yield and improve the agriculturally important qualities of a crop by mutation-breeding and secondly, producing high yielding varieties by means of chromosome doubling (polyploidy-breeding). I will now deal with recent development in these two new methods of breeding because they primarily come under the direct purview of Cytogenetics, and hold much promise for further improvement of our crop plants.

MUTATION-BREEDING

As is well known, mutations arise both spontaneously in nature, or can be induced in a variety of ways. Excepting the origin of sudden polyploids, trisomics ($2n+1$) and monosomics ($2n-1$) which can be classified as genomatic mutations and will be dealt separately, spontaneous mutations can be grouped roughly into three types according to their nature of origin : (1) *The intragenic changes* i.e., the point mutations or true gene mutations correlated to minor duplications or deficiencies which when expressed from chemical stand-point may only indicate addition of material by partial or complete polymerization of the substance of a gene-locus. It may also mean a loss of hereditary material by partial or complete depolymerization. Such a change is in the magnitude of submicroscopic or molecular level. (2) *Chromosome breakages*: These often arise as a result of deficiency at the point of breakage or it may arise as a result of co-operation with other breakages in creating duplications, inversions and translocations. (3) *Rearrangements of chromosome substance*: Such rearrangements occur as a result of crossing over, be it meiotic or somatic. This is the most common method by which chromosome differentiation originates.

The origin of these spontaneous mutations are often related to shocks produced by sudden differences in temperature or by natural radiations. Intracellular products of metabolism, either in natural or in abnormal conditions, may also act as mutagenic substance. These above types of events giving rise to different kinds of mutations also occur in case of artificially induced mutations whether these are produced by ionising radiations or by chemical mutagens. It is to be noted however, that the rate of occurrence of such events, i.e. induced mutations, will be very much greater than expected under natural conditions.

The study of genetic effects of radiation began with the discovery by Muller (1927) that some of the mutations produced by the effect of X-rays in *Drosophila* were indistinguishable from those occurring spontaneously in nature. It was also realized that the rate at which such mutations occur in irradiated population was very much greater than that found spontaneously in nature. Immediately after this discovery, Altenberg (1928) showed that X-rays induced structural changes in the chromosomes or brings about particular translocations similar to those found in natural mutations. In the case of plant material, it was Stadler (1928 a, b) who first observed genetic changes after application of X-rays in Barley and Maize.

While α, β and γ radiations of radioactive substances, X-rays, protons and neutrons are the most effective mutagenic sources ultraviolet light is the only non-ionizing radiation which is effective in this respect. "The principal means of energy dissipation by an ionizing radiation in its passage through matter is the ejection of electrons from atoms through which it passes. An atom so ionized is left positively charged and is referred to as an *ion*. The ions are localised along tracks, the lengths of which in the case of X-rays vary with the initial energies of the quanta and therefore inversely with the wave lengths. A quantum in ejecting an electron from an atom passes on some (Compton recoil electron production) or nearly all (photoelectron production) of its energy to the ejected electron. There is no difference in the properties of the recoil and photoelectrons. The ejected electron in its passage through matter causes further ionisation, losing energy with each collision until it finally halts. As the electron loses its energy the ionizations produced become more closely grouped. Thus the ionizations are not scattered uniformly along the whole track but occur in clusters widely spaced in the earlier part and more and more closely spaced in the later part of the track. The tracks of long wave lengths (soft) X-rays consist of little more than the densely ionized 'tail'. γ-rays are natural X-rays of very short wave lengths having quanta of very high energy and producing only Compton recoil electrons. α-rays are the nuclei of helium atoms, having only a short range in tissue and producing a very large number of ionizations per micron of path. Neutrons mainly project hydrogen nuclei, already in the tissue, at high speed as protons. These produce ionizations intermediate between electrons and α-rays in the density of their distribution along the track".

In 1943 Auerbach in Great Britain and Oehlkers in Germany independently, but convincingly proved that mutations can be induced by chemical agents both in animals and in plants. A little later Auerbach and Robson (1944) found that naturally occurring plant product, allylisothiocyanate has a weak mutagenic action on *Drosophila*. Since then, not only mustard gas but a large number of chemical compounds have been discovered which show remarkable mutagenic properties.

Quite an amount of data has also accumulated indicating that in certain conditions plants form substances of diverse chemical constitution which can act as mutagens on the plant itself. The most studied phenomenon in this respect is the probable production of mutagenic substances during the aging and decay of seeds (automutagenesis). Different views have been put forward to explain how the mutagenic substances (D'Amato and Hoffmann-Ostenhoff, 1956) arise in the cell, how the concentration of these substances already present in the cell may increase above the normal level during plant metabolism or how conditions inside the cell change to become more favourable for the action of an automutagenic substance which normally does not act as a mutagen in same concentration in the cell. It is of interest to learn that M. Nawashin as early as 1933 suggested that the death of the embryo in aged seeds might be the result of massive mutations in the embryonic tissues.

That artificially induced mutations, whether by ionizing irradiations or by chemical mutagens are similar to those produced spontaneously in nature, is due to the fact that the kind of changes produced, in the chromosome substance by such mutagens are similar to those created during spontaneous mutations. Therefore, spontaneous and induced mutations are not fundamentally different.

There has been good deal of scepticism about the scope for the production of improved varieties of crop plants by induced mutations. For it was known that a large number of mutations produced artificially are deleterious and do not survive. Also, methods are still not available by which mutations of desired kind may be induced each time with certainty in a particular crop. Use of radiation-induced mutations in plant breeding was first made by Nilsson-Ehle and Gustafsson in Sweden (Gustafsson, 1947) by the application of X-ray in Barley. They obtained varieties which were higher-yielding or had stiffer straws. Subsequently, Barley strains which were definite ecotypes for high and low nitrogen fertilizer or strains which were taller or shorter than the parents were produced (cf. Singleton, 1955). A number of useful mutations of crop plants have since been obtained by X-rays (e.g. Primex white mustard of Svaloff, Schaffer's universal in *Phaseolus*, higher-yielding strains of peanut, peanut resistant to leaf-spot and rust resistant strains of oat). With the increased supply of radioactive substances, after the remission of the last World War, superior variety of crop plants (cereals, peas, lupins, flax, tomatoes, etc.) have been produced by the application of such substances. It now, appears that the process of mutation to some extent can be controlled and directed by artificial means (McKey, 1954; Ehrenberg and Nybom, 1953-54). It is perhaps not realised sufficiently often that exposure to radiations can only induce genetic variability and by far the greater part of any plant improvement programme, whether based on natural or induced mutations consists of the subsequent breeding and selection from the progeny. As in the case of traditional plant breeding, mutation breeding also has been used with three classes of, crop plants i.e. self-pollinating, cross-pollinating and vegetatively propagating plants. It is among the self-pollinators which are genetically homozygous, except at locii at which mutation has covered within recent generations, that selection without mutagenic treatment may be expected *a-priori* to be least effective; and in point of fact it is with this class of plant that mutation breeding has been most used. Very few mutation-bred strains have yet reached the market, but this is partly because insufficient time has elapsed. In Sweden two mutant strains of Barley, one with short straw and the other being both early and short-strawed are now being multiplied for marketing. Barley strains with improved straw strength and mildew resistance have been reported in Germany and Austria. Rust-resistant wheats and oats have been produced in United States. A cooking type of pea with improved yield is being marketed in Sweden. An improved peanut has also been developed in the United States. It appears that the main value of using induced mutations in self-pollinating crops will be realised when it will be combined with subsequent hybridization and selection of such plants. Cross-pollinating plants usually show abundance of genetic variability in them and therefore, plant-breeders consider it unnecessary to increase further variation by irradiation. In spite of this in Sweden, strains of white mustard and rape with increased oil content have been successfully raised by mutation-breeding. In case of vegetatively reproducing plants, there have been no reports yet of the production of superior mutant strains by irradiation, although vigorous work in this direction is in progress in different parts of the world. Fruit trees like apple, peaches, grapes and various garden and ornamental plants have been irradiated with the hope of inducing bud mutations in them. New types of garden flowers have already been produced. New varieties of *Cyclamen* sp. have been produced in Holland and it appears that this particular species is a very good material for induction of mutations. It may be suggested that as in the case of colchicine-treated plants, repeated cutting back of new growth thereby stimulating the growth of dormant buds in vegetatively propagated shoot, may lead to the success of production of mutations in such plants.

It has been found in recent years that mutations may alter the reaction of plants to its normal environment and thus new ecotypes can be produced (e.g. ecotypes of barley reacting differently to different levels of nitrogen fertilizers). Application of this principle in case of crop plants would be of far reaching importance as strains suitable for a particular climatic condition can be produced which normally proved to be useless under that particular condition.

Similarly, mutation of crop plants apparently inferior to the cultivated types sometimes prove to be very important source of useful germplasm when transferred to cultivated types. Reference may be made here of the production of a superior malting variety of barley in Germany which, according to Schieman (1930) arose as a result of a cross between a mutation of inferior yield to another cultivated variety with week straw.

In our country attempt to artificially alter the germplasm of some economic plants with a view to raise improved types have been made since Ramiah, Parthasarathy and Ramanujam (1935) employed X-rays to both wet and dry paddy seeds. Parthasarathy (cf. 1953) has studied the progeny of these plants in detail and noted the formation of a ring of four chromosomes and the half-half segregation into fertile and sterile plants as being due to genetical non-disjunction. Ranjan (1940) has claimed to have produced improved strains of wheat, Jacob and Chowdhury (1954) high oil-yielding mutants of *sesamum* (till) and Chaudhuri (1948) tall mutants of Jute by application of X-rays. Bhaduri and Natarajan (1956) from a detailed study of the effect of nitrogen mustard to wheat have suggested that a higher rate of mutation could be obtained if lower dosage of nitrogen mastard is used of appropriate time. This method would also reduce the toxic action of the mutagen. Ramiah and Parthasarathy produced a mutation of paddy of dwarf habit but with larger number of tillers. They considered that this variety being less susceptible to lodging would be very suitable in rich soils (cf. Parthasarathy 1953). It is not known whether attempt was made simultaneously to transfer these characters of resistance to lodging and high number of tillers to some of the cultivated types.

In drawing any programme of work to improve crop plants by the application of radiations the following suggestions given by Whitehouse (cf. Proceedings of British Association Meetings, Sections D, I, K & M, Dublin, 1957) should be kept in view. According to Whitehouse the following radiation-induced genetic variability may prove to be valuable. (1) Where it is desired to add a single character to a delicately balanced genotype, as with rust-resistance in oat. (2) In vegetatively propagated plants where sexual reproduction will destroy the characteristics of the variety. (3) Where a desirable gene is known to exist but is unobtainable for biological, geographical or political reasons. (4) To extend the range of variability of a variable character in a sexually reproducing plant. (5) In special problem, such as breaking close linkage or transferring through chromosome fragmentation.

Reports of work from U.S.A., Sweden, U.K., Germany and other places indicate that mutation-breeding is done in well-equipped field laboratories by a band of workers. In India, on the other hand, work on similar lines have so far been carried out sporadically by individual workers, in rather unplanned manner in ill-equipped laboratories. Now it is necessary to undertake this work in an organised manner with properly planned programme of work in appropriate agricultural farms attached either to Agriculture Departments of Central and State Governments or attached to agricultural colleges of Universities and where modern appliances are available.

CHROMOSOME DOUBLING IN PLANT BREEDING

Since the discovery by Lutz (1907) and Gates (1909) independently of the *gigas* mutations of *Oenothera lamarckiana* to be polyploids, i.e. having chromosome numbers in multiple of that found in their parent, considerable interest was created among biologists who could find a clear and visible evidence of the physical basis of mutation in plants. Thus Gates (1915) analysed those mutations discovered by De Vries in terms of different kinds of chromosome change such as triploidy, tetraploidy and trisomy (2n + 1). In contrast to these, two other mutations of *O. lamarckiana*, *O. brevistylis* and *O. rubricalyx* were found to be gene mutations. The importance of polyploidy as a factor in evolution could be easily appreciated from the fact that most of our valuable crop plants such as wheat, cotton, tobacco, sugarcane, potato, banana, mango, mustard and coffee are polyploids, i.e. they have chromosome numbers in multiple series than those found in their relatives, either living or extinct, from which they have arisen by mutation and hybridization.

Although Digby (1912) discovered that the origin ot constantly fertile *Primula kewensis* which arose from sterile interspecific hybrid *P. verticillata* × *P. floribunda* being always associated with doubling of chromosome number, it was left to Winge (1917) who put forward the hypothesis of hybridization of species followed by doubling of chromosome number as one of the factor in the evolution of new species. Since then, it has not only been proved that a number of cultivated and wild species of plants have evolved following the above process, but by the application of colchicine a number of new species as well as some natural species have also been experimentally synthesised (cf. Stebbins 1955, Eigsti & Dustin 1956). Polyploidy has now become a separate branch of study and this new field of investigation has immense scope both from the point of view of fundamental studies as well as in its application for improvement of many crop plants.

The artificially induced autopolyploids, i.e., where the same chromosome set being multiplied, have been produced in a variety of both seed and vegetatively propagated crops respectively with varying amount of success. It has been found for instance that in the induced triploid sugar beet in Japan (Mochizuki and Matsumura, 1950), the sugar content is higher by 10 to 12 per cent than the normal diploid. Similarly Müntging (1951) in Sweden has produced a variety of winter hardy steel rye with comparable yield of the diploid but the baking quality of the flour and sprouting ability of seed of these tetraploids being very much superior to the diploid. Superior polyploid forage plants like *Trifolium hybridus* (alsike clover) and *T. pratens* (red clover) with higher forage yields have been produced (Turesson, 1949). Similarly in case of fruit trees, superior tetraploid cranberries and grapes have been produced (Dermen 1947, Olmo 1942). Triploid watermelon with very much higher yield than the diploid and tetraploid raddish with higher yield and club-root resistance have also been produced in the Kihara Institute, Japan.

It is now realised that different genotypes of a species respond differently to autopolyploidy and in order to improve a plant by this method, as many different genotypes as possible should be rendered polyploid. It is by subsequent breeding and selection of the recombined types as in the case of mutation breeding that the desired variety may be produced (Parthasarathy and Rajan 1933, Ramanujam and Parthasarathy 1954, Eigsti and Dustin 1956). In this respect, the programme of polyploidy breeding for self-fertilized and cross-fertilized crops have to be chalked out differently. For the self-fertilized crops a large number of genotypes but fewer plants from each type will be good enough as initial material for selection and breeding, but in case of cross fertilized crops selection and breeding have to be conducted in a very big population of tetraploids raised out of a few selected tetraploid genotypes. It is to be remembered that a very good diploid will not necessarily give rise to the best polyploid variety. In general it may be stated that cross fertilized or allogamous species are more promising as a group than the self-fertilizing types in the production of superior varieties of induced polyploid crops. Allopolyploids, i.e., those produced by hybridization followed by chromosome doubling, as is now known, are much balanced in their total-gene-complex than autopolyploids. Therefore, natural selection is more effective in the former than in the case of the latter. In order to establish superior varieties of plants with genotypical balance by polyploidy breeding, it is necessary that emphasis be given more to select varieties out of induced amphiploids or alloploids rather than on auto-ploids. Because, in these cases there is scope to combine the good characters of two different species. Many of our superior crop plants have evolved in nature following this process, we have only to copy these to our advantage. The situation in case of vegetatively propagated plants is quite different. As the problem of genotypical balance does not come into play in these plants the scope for polyploidy breeding and selection of superior varieties of induced polyploid crops are very much favoured. In India there is vast scope for the application of polyploidy breeding in the improvement of fruits, some of the vegetables and garden and ornamental plants. It is not clearly known whether the polyploid varieties of leguminous plants are superior nitrogen donors.

The success of inducing polyploidy by colchicine to plants varies considerably from one group to the other. However, suitable techniques are now available to the experimenters who can use them to different kinds of plants according to their requirements. For instance, hybrid embryos which do not grow normally can now be cultivated in artificial medium in sterile conditions and grown to a normal plant. These in turn, can be treated with colohicine in a normal way. When colchicine has to be applied to the seed certain difficulties are sometimes encountered and in some cases, seed treatment has been found to be a failure, e.g. maize, many cereals, some legumes and some endospermous dicotyledonous seeds. It appears that in these cases, colchicine action is deleterious to enzyme system of the seed. In such cases, growing dissected embryos in sterilized culture medium containing a suitable dose of colchicine has been found to be useful (Hyun, 1956 ; Bhaduri, unpublished work). In this connection it is to be remembered that our knowledge in regard to the mechanism of the action of colchicine to living cells is still very meagre and fundamental work in this field is very necessary. We have still to overcome the action of colohicine in inhibiting root development. If colchicine destroys the catalytic enzymes of the endosperms necessary for normal germination of seeds, and if the action of colchicine is a reversible one (Bhaduri 1939 ; Eigsti & Dustin 1956) then it may be possible in future to supplement these deficiencies artificially.

GENOME SUBSTITUTION AND GENOME ALTERATION

As stated before, one of the common practices of plant breeding is the selection of desirable recombination types, including chance amphidiploids from a segregating population. A new method of approach has been introduced in this field by the cytogeneticists in the study of polyploid plants and in their breeding methods. This method, i.e., the genome substitution and genome alteration can be employed only after a thorough analysis of the genomes are made of the particular crop in relation to its wild relatives. The term 'genome' was first employed by Winkler in 1920 to represent the haploid set of chromosomes. According to Casperi (1948) and Kihara (1951) who developed this line of work in case of wheat and related plants, a genome as represented by a chromosome set, is a fundamental genetical and physiological system whose completeness as to the basic gene content is indispensable for the normal development of the gametes and zygotes in haploid and diploid phases respectively. It follows, therefore, that there should be present at least one pair of complete homologous genomes in a fully viable and to a certain degree fertile polyploid species. The remaining complement may suffer changes or deficiencies and duplications which a dipliod plant can not tolerate. If the pairing of chromoscomes are identical and complete, it is assumed that the genomes are strictly homologous and the fertility of the plant is generally complete. On the amount of segmental similarity of pairing chromosomes, the manner of pairing and to a considerable extent the fertility of the species will be conditioned.

Genome analysis based on types of chromosome pairing have been made extensively with wheat, tobacco, cotton, etc., amongst the important crops. Such a study has not only helped in assessing the affinities of these crops in relation to their allied species in the artificial synthesis of these crops from their elemental species, but also opened up the scope for the introduction of useful genomes in these crops by wider intergeneric crosses. The introduction of *Aegilops, Agropyron, Secale* and *Haynaldia* genomes in *Triticum aestivum* (the bread wheat) by different workers may be cited as illustrations. In such experiments involving genome transference, it is of prime importance, however, to keep in view the rôle, the plasma of the female parent would play in the manifestation of the degree of fertility. Kihara (1951) has described methods for complete substitution of genome in polyploid species by successive backcrosses assuming both complete and partial homology between genomes. Where the two genomes are non-homologous with only univalents and unreduced gametes in F_1, he has pointed out that the process of genome-substitution by successive backcrosses would be greatly simplified if doubling of the chromosomes could be made by the application of colchicine.

There is great scope for the study of genome analysis and genome substitution in many of our grain and fruit crops in India. Paddy is a secondarily balanced polyploid species as compared to allopolyploid crops like bread wheat, cotton and tobacco, and methods applicable to these crops cannot be used straight away in case of paddy. For this purpose, amphiploids involving different species of *Oryza* and related genera and different varieties of paddy including indica-japonica hybrid should be first produced. Study of genome substitution and genome analysis in these induced amphiploids is bound to produce valuable data leading to the production of new and improved varieties. From such studies also, a more clear understanding as to the origin of the cultivated *Oryza sativa* and its phylogenetic relationship to other related plants would be gained.

Instead of replacing one full genome, attempts have also been made by a few investigators to substitute only one or a pair of chromosome in polyploid species. Analysis of characters such as disease resistance, earliness or lateness of the crop as well as the quality and yield of grains in a crop can be very well studied in such plants with substituted chromosomes (Sears 1956). Sears (1955, 1957) has also been able to produce the full series of 21 nullisomics (i.e. 40 instead of 42 chromosomed bread wheat) in the Chinese spring wheat. These nullisomics have made it possible to establish each chromosome from a variety of wheat in a substitution line having 20 pairs of chromosomes from Chinese spring and a single pair from the donor variety. These substitution lines of Chinese spring containing chromosome substitutions from well known varieties such as Hope, Thatcher, Red Egyptian and Timstein, have been tested for resistance to a number of cultures of stem rust. It has been observed that chromesomes VIII and XVII from Hope; III, XIII and

XIX from Thatcher ; VI, XIII, XX from Red Egyptian ; X from Timstein ; and XI from Chinese spring carry genes for resistance to one or more of the cultures of the pathogen. Work on the above line has been initiated in the Indian Agricultural Research Institute, New Delhi, and it is most desirable that such work should be extended to other economic crops wherever monosomic or nullisomic plants can be obtained. In case of paddy such work may prove to be very profitable in artificially produced amphiploids.

KARYOTYPE ALTERATION

Another line of cytogenetical investigation which has already contributed significantly in establishing affinities of crop plants to their wild relatives, and also in the isolation of new mutations, is the karyotype analysis of such groups of plants. Karyotype of a species represent the particular morphological pattern of the genomic set of chromosomes in that species. It has been found that the karyotype of a sexually reproducing species is constant and genetically controlled. On the assumption of certain cytological criteria (e.g. symmetrical and asymmetrical types of chromosome complement, smaller or larger chromatin content of the chromosome complement, number of satellited chromosomes in their relation to corresponding number of nucleoli present in that species, the number and location of heterochromatic knobs or segments in chromosomes etc.) the relative position of the species under investigation in the evolutionary history of that group can be worked out (Gates, 1942 ; Bhaduri, 1944, 1946, 1947 ; Sharma, 1956 , Stebbins 1955). In plants with symmetric karyotypes the satellited chromosomes of the complement is made use of as marker chromosomes in breeding and selection work ; in asymmetric types, several chromosomes may be identifiable as markers. As the sat-chromosomes are also nucleolar chromosomes, and as the number and size relationship of the nucleoli are constant characters controlled by genes, any visible change produced in the karyotype due to mutation or increase or decrease of the maximum number of nucleoli can easily be detected. Such changes may or may not be accompanied by corresponding phenotypic changes (Bhaduri, 1942 ; Bhaduri and Sharma, 1949). Alterations in the karyotype of a species may occur both spontaneously in nature or be induced by artificial means. If such altered karyotype enter into the germ track, it may then ultimately lead to the evolution of a new mutation (e.g. Gerassimova, 1930, in *Crepis.*) Occurrence of chromosomal races differing from their parental type with respect to number of sat-chromosomes or karyotypes have been established in a number of instances (Nawaschin, 1927, 1934 ; Bhaduri, 1942, 1944 ; Bhaduri and Sharma, 1949 ; Bhaduri and Ghose, 1954 ; Bhaduri and Natarajan 1956b and Müntzing, 1954). That some of the improved varieties of crop plants are chromosomal races or biotypes is supported by the fact that C/591, i.e., the common Punjab variety of wheat, has been found to possess a different karyotype than the other commonly cultivated strains (Bhaduri and Natarajan, 1956a). Such spontaneous alterations in the karyotype have been observed by many workers in the case of vegetatively propagated plants (Sato, 1942; Bhaduri, 1944; Sharma, 1956). Although there is a possibility of such cells developing into a mutant clone, experimental evidence to substantiate this view have yet to come.

Species having high chromosome numbers but without showing evidence of their polyploid nature have been reported. It is believed that these species with high numbers of chromosome, yet indicating diploid nature, have evolved by repeated duplication of chromosome sets following hybridization (amphiploidy). It is generally accepted however, that speciation is correleted to minute rearrangements in chromosome substance, gross structural change of chromosomes or increase in the quantity of hereditary substance directly or following hybridization. All these changes after all, provides building up of additional new possibilities of recombination types. If it is assumed that particular acentric types of fragments produced as a result of segmentation of chromosomes at particular loci can develop its own centromere under certain conditions, then it follows that by segmentation of a long chromosome at particular loci i.e. secondary constriction regions, into more than one unit, the number of chromosomes in the cell may be proportionately increased. As a consequence to such an increase in chromosome number, the number of possible recombination types in such plants will be increased enormously. Natural selection on such a population will be more effective and will eventually isolate new species. Direct evidence of the origin of new species by this method is not available but a hypothesis supported by an amount of data suggesting segmentation of chromosomes at particular loci into smaller units of chromosomes was put forward a few years ago (Bhaduri, 1947; Chakrabarty, 1949). In support of this view, a proportionate increase in the number of nucleoli and satellited chromosomes in these species with higher chromosome number were recorded. In view of the fact that instances of chromosomes having diffuse type of centromere are being discovered and segments produced by X-rays out of such chromosomes remained viable during nuclear divisions (Castro *et al.*, 1949), the theory of segmentation of chromosomes as a factor of variation and evolution gets further support. Evidences are also accumulating indicating occurrence of chromosomes with diffuse centromere in many lower plants (Vaarama, 1954; Godward, 1950). It has also been found that such chromosome like bodies may divide transversely instead of longitudinally during cell division. From such a primitive condition of the nucleus where hereditary substance is located in large and a few chromsomes with diffuse centromere, the evolution of many chromosomes with a single centromere can be visualised. More extensive work on the breakages of chromosomes by X-rays and other radiations on suitable plant and animal material is necessary to settle this controversial theory. This method may eventually prove very important in creating variations in plants which form the basis for the improvement of the existing types.

CONCLUSION

We are conscious of the increasing demand in our country for greater supply of food to our underfed and rapidly growing population. We are also aware of the fact that the average yields of our important crops are far below the standard achieved in other progressive countries. There is no doubt that part of this shortage of food can be made up by increasing the average yield per acre following better agricultural practices, supplying to the cultivators pedigree seeds, providing irrigation facilities, supplying artificial fertilisers and by following better practices of crop husbandry. Our Government being fully aware of these facts have already taken necessary short and long term measures so that production of food crops may be increased. It can not be overlooked however, that the most economical and conspicuously effective method, though long ranged but very often not sufficiently appreciated, for increasing the yield and quality of crops would be to breed superior varieties of crops suited to specific and changing ecological conditions and special local requirements including resistance to diseases. Although a number of improved varieties of crop plants have been produced in India during the last 50 years, even then we have yet to improve these crops with respect to their yield, resistance to diseases and better qualities. Further, there are a number of crops which have not been tackled in a methodical and scientific way or not tackled at all. In such an endeavour to improve the crops, application of traditional methods of plant breeding following Mendellian principles or direct introduction of foreign plants from analogous climatic conditions will always have a limited scope. In this context, that application of cytogenetical methods in the production of improved varieties of crops as indicated in my address have to be employed needs no special emphasis.

I have indicated that success in such research work depend on proper planning of research programme for each crop and by organised and combined effort of a team of workers including plant breeders, radiation geneticists, cytogeneticists, plant physiologists and plant pathologists in agricultural farms equipped with modern appliances. In order to put the above principle into practice I consider that the following additional organisational measures on an all-India basis have to be taken simultaneously.

1. Encouragement of fundamental research in genetics and experimental cytology in universities, agricultural and allied research stations.
2. Introduction of and laying more emphasis to teaching of modern genetics, experimental cytology and applied botany in the curriculla of universities and agricultural colleges.
3. Creating centres of research for advanced training in modern methods of plant breeding on a zonal basis.

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SECTION OF PHYSIOLOGY

President :—DR. S. N. RAY, M.Sc., Ph.D.

PRESIDENTIAL ADDRESS

RUMINANT METABOLISM

I am deeply sensible of the great honour done to me by my colleagues in the Sectional Committee by electing me as the President of this Section. This is all the more gratifying because in the long list of my illustrious predecessors, I am the second worker in the field of animal husbandry who has been selected for such a signal honour. This I may attribute to the recognition of the growing importance of animal husbandry in general and animal nutrition in particular in relation to public health and other problems.

I intend to take up the subject of Ruminant metabolism and to point out several interesting aspects in which the nutritional behaviour of cows, sheep and goats differs from that of man or the common laboratory animals.

The most salient feature of ruminant nutrition is the remarkable symbiosis between the host and the vast population of microflora which thrive in the rumen, the first and the largest of the four stomachs. With the aid of these bacteria and protozoa, the cellulose, hemicelluloses and even simpler carbohydrates of the feeding stuffs are broken down into volatile fatty acids like acetic, propionic, butyric and valeric acids. These acids are absorbed mostly directly through the rumen wall and thereby enter into the cycles of intermediary metabolism. A portion of the carbohydrates of the feeds is converted into bacterial and protozoal polysaccharides, which are later on hydrolysed into hexoses in the lower parts of the alimentary canal but their quantitative importance in supplying the energy needs is much smaller than that supplied by the volatile fatty acids. By choosing to ferment the resistant fodder constituent cellulose at the beginning rather than at the end of its digestive tract viz., large intestine as in horses and rabbits, the ruminant is able to utilise more fully the coarse fodders like straw and hays. In fact, it has been found that 70-85 per cent of the digestible dry matter of the ration disappears during its passage through the rumen (Gray, 1947). The fermentations in the rumen overshadow entirely the rest of the digestion in the alimentary tract, (Blaxter, 1954). Such behaviour enables the ruminant to help the human social economy as they can to a great extent utilise and convert the byproducts of human feeds like straws, brans, cakes, etc., into highly nutritious products like meat and milk.

This unique property of ruminants of conversion of coarse roughages into useful product is, however, not a very efficient process. In the first place, the animal can digest roughly 50-60 per cent of the gross energy of coarse feeds. This point will be referred to later. However, even the digested nutrients can only be partially utilised by ruminants for production purposes. In a non-ruminant or even in a calf whose rumen has not started functioning, some 15 per cent of the metabolisable energy is lost as heat increment, but in an adult ruminant, losses of heat amounting to 30-50 per cent of the metabolisable energy take place. A portion of the heat generated is useful in keeping the body warm, particularly during the cold seasons, but otherwise the heat loss represents inefficiency in converting the energy present in the feed into a product viz., body gain, milk or work. In summer, as the environmental temperature increases, ruminants, being non-sweating in nature, try to dissipate the heat generated internally by augmenting vaporisation from the respiratory passages, through a rapid rise in the respiration rates. The latter has been found to rise from 10 per minute at 60°F to 40 per minute at 100°F (Mullick and Kehar, 1952). This puts a stress on the body system of the ruminants so that production capacity diminishes greatly at temperature ranges over 95°F.

A further interesting feature is that the amount of energy lost as heat varies with the type of feed and is maximal with feeds of high fibre content. That an increase in cellulose content of a ration has nothing to do with extra heat loss had been shown by such pioneer workers like Kellner who showed that pure cellulose can be utilised nearly as efficiently as other carbohydrates. Recently, Marston (1948) digested pure cellulose in an artificial rumen and found that 6 per cent of the energy is lost as heat and 8 per cent as methane, leaving 86 per cent of products which can be utilised for metabolic purposes. The figure tallies very well with the 15 per cent as heat loss in simple stomached animals. This loss of 30-50 per cent of metabolisable energy as heat by ruminants is, therefore, a phenomenon which is still not fully understood. Some energy is of course lost in the thorough mastication of coarse and fibrous feeds and Kellner in fact designated the heat lost as "work of digestion" but Armsby and others do not agree with this concept as the extra work done in mastication cannot account wholly for the production of so much heat. As a matter of fact, even when coarse fodders, high in fibre content, are fed in a powdered form so that the work done in mastication is very much lessened, the heat loss still remains nearly as high as that with the untreated feeds. Blaxter (1952), therefore, assumes that utilisation of volatile fatty acids—the chief products of cellulose disintegration in the rumen—is associated with an appreciable loss of energy as heat and this is the tax the ruminants have to pay for the symbiotic action of the microflora of the rumen.

Forbes *et al* (1926) postulate that 69·5 per cent the metabolisable energy in a well balanced mixed ration is available for maintenance of an idle animal while only 57·7 per cent can be utilised for body gain and 63·0 per cent for milk production. The type of feed used for these experiments was not very high in fibre content. With very coarse type of roughages like straw or with imbalanced rations, the per cent availability will be still lower. This complex nature of differential feed utilisation makes it difficult to lay down rigid standards of feeding as requirements vary not only with body weight of the animals but also on the types of rations used. In order to obviate this difficulty, present feeding scales are generally too generous so as to cover all cases under different feeding regimes. The following data will illustrate the point stressed above. Kriss (1921) has stated that an intake of 5·25 lb. total digestible nutrients (TDN = digestible carbohydrates plus digestible protein plus digestible fat × 2·25) is the maintenance requirement of an idle, non-producing animal of 1000 lb. body weight. According to Brody (1945) 1 lb. Total digestible nutrient contains 1814 Kcal so that the energy requirement of such an animal will be about 9525 Kcal per day. This value is nearly of the same order of 2400 Kcal as required by a man of sedentary habit and of body weight 150 lb., assuming that the energy requirement is proportional to body weight raised to a power 0·7. Brody (*loc. cit.*), however, puts forth the energy requirement to be 12200 Kcal (=6·75 lb. TDN) while Morrison (1956) and the Nutritional Research Council (U.S.A.) advocate an allowance of 8 lb. TDN/1000 lb. body weight, in ruminants.

Very little work has yet been done in India to find out the energy requirement of ruminants under Indian conditions of feeding and climate. A beginning has been made at Izatnagar to find out the maintenance requiremet of non-producing cattle and the data obtained so far indicate much lower values as compared to Western figures. Kehar, Mullick and Thakuria (1955) have found the daily heat production of an idle bullock to be 9600 Kcal per day per 1000 lb. of body weight. This figure obtained in animals kept on a basal ration of coarse roughage like wheat straw is similar to that found by Kriss (1931), with better quality feeds but is lower than the other figures given in the previous para. No work has been done so far to find out the percentage of metabolisable energy which can be utilised by our cattle for production purpose. Such work is necessary before standard feeding schedules for cattle under Indian conditions of management can be laid down.

PROTEIN METABOLISM

The part played by the rumen microflora in the nutritional physiology of the ruminant animal is not restricted to the utilisation of cellulose and hemicelluloses. With the symbiotic action of these micro-organisms, ruminants can also use for both maintenance and production purposes, such simple nitrogenous compounds like urea and ammonium salts-compounds which are useless in simple stomached animals as source for body or milk proteins.

The first stage in the utilisation of nitrogenous compounds that takes place in the rumen is the liberation of ammonia from soluble proteins or compounds like urea, ammonium salts, choline, betain and even nitrites and nitrates (Lewis, 1951). Simultaneously certain rumen microflora convert the liberated ammonia into their body protein, provided sufficient energy yielding substances of proper quality are also present. The microbial proteins are afterwards digested in the fourth or the real stomach, and supplies the host with the necessary amino-acids. Nitrogen utilisation and energy utilisation in the rumen are, therefore, closely linked. Of all the common energy yielding substances ,starch is the best as its rate of fermentation parallels the liberation of ammonia from amides. Hexoses or cellulose are not so efficient, the former because they are too quickly fermented and the latter because of its comparatively slower breakdown. If the liberated ammonia is not quickly trapped, it is absorbed through the rumen wall and is conveyed by the portal blood to the liver where it is converted into urea which is mostly excreted in the urine. The microbial protein formed from urea in presence of starch has a high biological value of about 88 per cent (Reed *et al*, 1949), indicating the capability of the micro-organisms to synthesise essential amino-acids from ammonia.

Loosli *et al* (1949) using a nearly protein-free diet containing urea as the sole source of nitrogen found that the protein isolated from rumen contained all the essential amino acids and the animal further excreted 3-10 times as much of each of such acids as was present in the ration. These facts show that the ruminant is not so dependent on the quality of feed protein as are single stomached animals for maintenance or growth.

While it has been possible to maintain ruminants by supplying urea along with ample starch, a little consideration will show that such a ration will be not only uneconomical but also largely inefficient. The main utility of ruminants as livestock lies in their power to utilise coarse fodders rich in cellulose. A ration high in starch content depresses the digestibility of cellulose. Further, as already stated, the action of cellulytic microflora is comparatively slower than that of bacteria fermenting starch and soluble sugars. As the liberation of ammonia from urea is rather quick in the rumen, most of it is either trapped by the latter type of bacteria or absorbed into the portal blood system, so that the cellulytic organisms are unable to proliferate in the absence of a source of nitrogen. Certain amount of protein which are deaminated sufficiently slowly to be utilised by these cellulose-splitting organisms need, therefore, be present in the ration for the most efficient utilisation of coarse fodders. Such proteins are usually present in leguminous fodders or early cut hays and this in part explains the beneficial use of green feeds in the ration of ruminants. The microbial protein and polysaccharides formed in these cellulytic anaerobes can also be used later by the ruminants by digestion in the abomasum and the small intetstine. It follows, therefore, that for maximum microbial activity for both cellulose breakdown and protein synthesis, some soluble proteins should be present in the ration. Urea can safely replace on a nitrogen basis upto a third of the protein in the ration of ruminants, provided sufficient starch is simultaneously supplied (Rein, 1953).

This explains why urea has been successfully used as a protein replacement in the U.S.A. though it has found very little support in the Europen system of stock feeding. In U.S.A. the rations contain large quantity of maize which supplies the starch necessary for efficient conversion of ammonia from urea. The emphasis in the U.K. and European countries is to maintain the ruminants on high quality herbage either through grazing or as silage. In winter months, root crops are also used to supplement the ration. The prevalence of non-starch energy sources creates conditions that militate against the use of simple nitrogenous compounds as protein replacement. In fact the F.A.O. International meeting held at Zurich in 1949 commented that "At present urea or other feeding stuffs based on amides are not used in European countries since they have proved unsatisfactory under European conditions". If this is the case in Europe, it is doubtful how far the employment of urea or ammonium compounds will be of practical value under Indian conditions where protein deficiency is the major factor for low productivity of livestock. The most easily available source of starch in livestock feeding is provided by cereal grains which are themselves in short supply due to the demand on them for human consumption. In the South, where tapioca is grown in large quantities, this root which is rich in starch and low in fibre content (Kehar, 1953, 2), can perhaps be used in livestock feeding by supplementation with urea.

The utilisation of protein nitrogen can be improved by supplying feeds containing easily digestible higher carbohydrates. It has been well established from numerous works carried out in India that the digestibility of coarse fibre and indeed of the total organic matter present in a plant diminishes with its maturity. Thus, the digestibility co-efficients of organic matter and crude fibre in young guinea grass are 77 and 78 per cent whereas in its flowering stage the values are 53 and 60 per cent respectively. These differences are due to greater lignin deposition in mature plant which renders the cellulose and other complex carbohydrates less available to the rumen microflora. It has been found that treatment with dilute alkalies can improve considerably the digestibility of the carbohydrate moiety of coarse food (Sen, *et al*, 1942). Thus the digestibility coefficient of carbohydrates was found to increase from 51 per cent in the untreated wheat straw to 72 per cent in alkali treated straw. Simultaneously the nitrogen balance was increased from 1·2 gm. to 13·0 gm. daily with the same nitrogen intake. This result is what is to be expected in view of the fact outlined before. In presence of easily available carbohydrates, the rumen microflora have better opportunity of trapping the ammonia released from proteins and amides present in the ration and comparatively much less ammonia can be directly absorbed into the portal blood through the rumen wall. Fats are less efficient in this nitrogen sparing action. When the carbohydrates of the ration are replaced isocalorically by fats or oils, the digestibility of feed protein is increased but urinary nitrogen excretion is enhanced greatly, resulting in a less total nitrogen retention (Ray, *et al*, 1952).

The endogenous urinary nitrogen secretion (E.U.N.) in an adult ruminant of 1000 lb. body weight has been found by western workers to be about 15 g. daily. This value may be compared with about 3·5 g. in a man weighing 150 lb. These two values are of the same order if we assume that urinary nitrogen secretion on a protein free diet is proportional to $W^{0.7}$ where W is the body weight of the animal (Brody, 1945). On the other hand, metabolic faecal nitrogen (M.F.N.) i.e., the amount of nitrogen excreted in the faeces by an animal on a nitrogen free ration is much higher in the ruminant than in simple stomached animals. Thus the value is 0·4 to 0·5 g nitrogen per 100 g dry material ingested in ruminants as compared to 0·1 to 0·2 g nitrogen /100 g. feed in rats or man (Blaxter and Mitchell, 1948). As the dry matter ingestion in a 1000 lb. idle bullock is about 8 kg., its metabolic fecal nitrogen secretion will be about 40 g. The total daily body loss of nitrogen on a nitrogen free diet in such an animal through urine and faeces will be about 55 g. By a factorial method after correcting for true digestibility and biological value of feed protein, the digestible crude protein intake for maintenance of this class of animal can be found to be 0·7 lb. per day. This value agrees very well with the figure of 0·625 lb. as recommended by Morrison (1956) from actual feeding trials. In contrast, Kehar and Mukherjee (1947) showed that the M.F.N. is 0·35 g/100 g dry matter and E.U.N. is 10 g/1000 lb. body weight. From these values the daily digestible crude protein requirement of Indian animal can be calculated to be 0·4 lb., a value 33 per cent lower than that for western animals of similar body weight. As a matter of fact, Mukherjee and Kehar (1943) have shown that indigenous bullocks can be kept in nitrogen balance on a ration containing 0·4 lb. of digestible protein per 1000 lb. live weight. More recent and extensive experiments at Izatnagar with both indigenous bullocks and buffalo bulls have corroborated this figure. These results indicate that the Indian animals have perhaps a lower basal metabolic rate resulting in less body heat and urinary nitrogen output. Also perhaps their intestinal mucous membranes are more resistant to the frictional action of fibrous feed residues.

Goswamy (1954) while studying the cause of low digestibility coefficient of the protein present in certain tree leaves found a high content of tannic acid in such sources. Addition of tannic acid to a ration low in this acid was found by him to lower the digestibility of protein in both rats and cattle. The mechanism of this antagonistic action of tannic acid in protein metabolism yet remains to be investigated.

MINERAL METABOLISM

Calcium and phosphorus

Of all the minerals, the greatest attention has been given in India and elsewhere on the metabolism of calcium and phosphorus. Yet, inspite of a large volume of available data, the question of minimum requirement of these two minerals for adult cattle yet remains more or less unsolved. Thus, values from 32 g to 8 g of calcium and 10 g to 5 g of phosphorus per 1000 lb. body weight have been found by different workers. The reason lies in the fact that the normal adult has limited capacity for storing these minerals so that a small positive balance (or even sometime a negative balance due to errors in sampling) may be observed at all levels higher than a certain minimum intake. A large number of investigations with different levels of calcium and phosphorus intakes and of sufficient duration are necessary before the minimum values may be satisfactorily established. Use of radioactive isotopes may prove to be of great value in such researches. Further the requirements are found to vary widely with the types of roughages fed. Thus, with wheat bhoosa, positive calcium and phophoruss balances have been struck with intakes of 16 g. of calcium and 10 g. phosphorus respectively/1000 lb. body weight (Majumdar and Ray, 1946). Similar figures on a ration containing paddy straw were as high as 34 g. of calcium and 9 g. of phosphorus (Carbery *et al*, 1937). This high calcium requirement on a paddy straw feeding regime has later been found to be due to the high content of oxalates in this roughage. However, unlike in simple stomached animals, oxalates fed to ruminants do not immobilise the calcium of the feed as calcium oxalate as was shown by the low content of this salt in the faeces of cattle getting large doses of added oxalates. It is presumed that oxalates are oxidised into carbonates in the rumen. The resultant alkalosis prevents later on the mobilisation of feed calcium in the lower parts of the alimentary canal (Talapatra *et al*, 1942). Treatment with alkali or mere washing with water removes the bulk of oxalates from paddy straw and animals of about 500 lb. body weight receiving the treated straws were found to show positive balance of calcium on an intake of 10 gm. of this mineral.

Even with the same species of fodder, calcium and phosphorus utilisation has been found to diminish with the maturity of the plants (Iyer, 1935). All these considerations show how difficult it is to lay down figures of minimum calcium and phosphorus requirements which can hold good under all circumstances. However, for general practical purposes, the requirements can be taken to be 15 g. of calcium and 10 g. of phosphorus for a 1000 lb. adult non-producing cattle. With paddy straw as the roughage fed, the provision of calcium should be 2-3 times as much. These high values may be compared with the figures of 0·55 g. of calcium required by an adult human of 150 lb. body weight (Leitch, 1937).

Cattle are found to be less affected by the calcium and phosphorus ratio of the feeds. No ill effect has been seen even on such a wide ratio of Ca : P = 10 : 1 provided minimum required quantities of phosphorus is present. However, when such adverse balances exist, the animals are more prone to the toxic action of certain elements like fluorine. Majumdar and Ray (1946) have shown that on an adequate ration containing calcium and phosphorus in proper balance, administration of 3 mg. of fluorine per kg. of body weight could induce symptoms of fluorine intoxication only after 2-3 years' continued intake. On the other hand, with rations having a ratio of Ca : P = 1 : 4 or 4 : 1, fluorosis could be induced within 9-12 months of feeding.

Under the usual feeding conditions prevalent in India, calcium deficiecny is not likely in non-producing animals, as the usual roughages fed contain sufficient amount of this mineral. In regions where paddy straw is fed, a deficiency, however, may exist as explained before. In growing and lactating animals, however, calcium deficiency is likely to occur as the concentrates used for production purpose are generally poor soures of this mineral. On the other hand, such concentrates are rich in phosphorus, whereas, straws and hays made of ripe grasses have a low content of this mineral. Nevertheless, clear cut cases of calcium and phosphorus deficiency, though extensively reported from South Africa and parts of Australia, have not been seen under field conditions in India. This is due to the comparatively small size and low productive capacity of Indian animals. Improvement in milk yield of cows and growth rate of calves has been obtained in several Indian farms through supplementation of the basal ration with mineral mixture containing calcium and phosphorus, indicating thereby a suboptimal intake of these minerals in animals at such places previously.

Magnesium

Definite conclusions regarding minimum requirement of this mineral are still lacking. On different types of rations the requirement had been found to vary from 4-15 g. per 1000 lb. body weight (Sen, 1953). However, magnesium is usually present in such ample quantities in a mixed ration that very seldom a negative balance in this mineral is met with under Indian conditions of feeding. Tetany in animals has been produced artificially on certain types of feeds and a low magnesium content in the blood serum has been observed in the affected animals (Ray, 1943, Blaxter *et al,* 1954). Under field conditions, however, this is a rare syndrome in India. Certain workers in the U.K., Holland and New Zealand have attributed magnesium deficiency as the cause of "grass tetany" or lactation tetany' on the basis of low magnesium content of blood serum in the affected animals. (Sjollema, 1930; Allcroft and Green, 1934; Stewart, 1949). The fall in blood magnesium could not, however, be correlated with any variation or deficiency in the magnesium content of the diet, though outbreaks of lactation tetany can be controlled through injections of massive doses of magnesium salts. It appears, therefore, that the field cases reported by foreign workers cannot be regarded as of nutritional origin but more probably caused by a failure to mobilise body magnesium due to some endocrine dysfunction.

Sodium, potassium and chlorine

Insufficient data exist regarding the minimum requirement of these minerals for ruminants. Potassium is usually present in fair abundance in grass and straw so that its deficiency is very unlikely. On the other hand, sodium and chlorine contents of animals feeds are usually low so that a supplement of common salt is necessary particularly for milch animals. Common salt acts also as a condiment in increasing the dry matter intake of animals specially in those getting coarse roughages like straw.

Iron

The requirement of iron in sheep has been studied by Murty (1953) who advocates that a ration containing 212 p.p.m. of total iron or 91 p.p.m. of available iron to be sufficient for its maintenance. The usual rations fed to ruminants, however, contain sufficient quantity of this mineral so that a deficiency of iron under field conditions is unlikely, unless young lambs or calves are maintained for an unduly prolonged period on milk alone.

Copper

Sahai (1948) by carrying out metabolism trials in cattle with different levels of copper intake, has put forward the requirement of this mineral to be 6·5 mg/100 lb. body weight. This value corresponds very well with the findings of Australian workers that copper deficiency in ruminants can be prevented when kept on a ration containing 7 p.p.m. of copper. The human requirement of 1-2 mg. in an adult weighing 150 lb. (Chou and Adolph, 1935) is, therefore, five to ten times lower. In view of this high requirement, cattle and sheep in many countries of the world have been found to suffer from copper deficiency. Ataxia, stringy wool, depigmentation of hair, anaemia, etc., are the common symptoms (Russell and Duncan, 1956). Sahai and Kehar /1951) have reported low copper content in many common Indian feeds like straws and hays. A survey of about 40 farms in India has revealed a subnormal copper intake in about a dozen places. The haemoglobin content of the blood of calves in these latter farms was also found to be below the normal level. Addition of copper containing mineral mixtures has been found to be effective in raising the haemoglobin content to normal values (Ray and Zubairy, 1955; Dutt and Ray, 1956).

In certain regions, however, low copper content of blood and liver has been observed even when the content of this mineral is quite high in the pasture grass. In some places, like Somerset in England and California in U.S.A., Manitoba in New Zealand or in parts of Ireland, a high molybdenum content (over 10 p.p.m.) of the pasture has been found to interfere with the mobilisation of feed copper. Such cases can be called as induced copper deficiency and can be relieved by giving massive doses of this mineral. In other places like Aberdeenshire, Cheshire, and Cambridgeshire, low copper content of blood and liver has, however, been found in animals grazing on pastures high in copper and low in molybdenum contents. Recently Dick (1953) has produced copper deficiency symptoms in sheep receiving adequate copper, subtoxic dose of molybdenum but getting extra inorganic sulphate. Whether a high sulphate content of the forage is a causative factor in inducing copper deficiency in parts of U.K. still remains to be explored. Our own investigation shows that a level of 10 p.p.m. of molybdenum in the ration can affect within 2 months the haemoglobin status of an animal even when the copper intake is 6 mg/100 lb. body weight.

Cobalt

Only ruminants have so far been found to require cobalt in their feed. Cyano-Cobalamin or vitamin B_{12} is necessary for many species but the requirement in non-ruminants is so small that attempts to produce anaemia by giving a cobalt-low diet to simple stomached animals have failed up till now. Even in ruminants, cobalt should be administered orally as injections of cobalt salts have been found ineffective to cure cobalt deficiency symptoms (Ray *et al,* 1948). The requirement of cobalt is extremely small being only 0·047 mg./100 lb. as found by Singh (1948) from metabolism trials, though Stewart *et al* (1945) recommends a level of 0·1 p.p.m. on dry matter basis in the forages fed.

The main function of cobalt in ruminants seems to be the production of cobalamins, as injections of vitamin B_{12} have been found to cure symptoms of cobalt deficiency like anorexia, loss in weight and anaemia. The dosage is, however, very high being of the order of 45 micrograms per day in a lamb weighing 50 lb. (Smith *et al,* 1951). In contrast, the doses employed in the treatment of human pernicious anaemia are only 2-4 micrograms per day. A deficiency of cobalt has also been found to reduce the riboflavin, pyridoxine and nicotinic acid contents of blood in sheep (Ray *et al,* 1957).

Cobalt deficiency has been found in sheep and cattle in Australia, U.S.A. and U.K., but not so far in India.

Manganese

The maintenance requirement of managanese in cattle has been found by Sawhney (1951) to be 37·5 mg./100 lb. body weight. This amount is easily provided through the rations commonly fed and manganese deficiency seems remote under field conditions. On the other hand, a very high level of manganese content is seen in paddy straw (Kehar and Sawhney, 1952; Ray and Zubairy, 1955). Whether such high intakes are detrimental remains yet to be examined.

Iodine

Goitre has been found prevalent in ruminants, particularly in the foot hills of the Himalayan range. Dutt (1954) has shown that such occurrences are much more common in goats than in other species of ruminants. Beneficial effect of feeding iodide salts to cattle on their milk production, resistance against diahorrea and smooth hair coats have been reported by some Indian workers (Matson, 1931; Nayudu, 1931).

Vitamins

The adult ruminant is in the happy position that it is to a great extent not dependant on its diet for a large number of vitamins. Thus, the microflora of the rumen can synthesise all the B-complex vitamins as well as vitamin K provided sufficient cobalt is also simultaneously present. Suckling calves, in which a functional rumen has not yet developed do need preformed thiamin, riboflavin and biotin but their supply is adequately met, provided sufficient colostrum and milk are given. Vitamin C is synthesised within the body tissues, as calves can be reared on a vitamin-C-free diet for over a year without the blood content of the vitamin being even slightly affected (Ray, *et al,* 1941). Any ascorbic acid added to the ration is, however, quickly destroyed in the rumen. Injection of paraldehyde or barbitone is found to enhance the synthesis of vitamin C in ruminants (Ray, 1942). In certain infectious diseases or in helminthic infestation, the vitamin C content of blood and liver is diminished, showing that endogenous production of the vitamin is not sufficient to meet the enhanced metabolism caused through diseased conditions (Ray, 1941). Of the fat-soluble vitamins, vitamin D is not required under the tropical conditions due to the abundance of sunshine. Rickets in farm animals has not been reported at all in this country. Deficiency of vitamin E has been found to produce certain types of muscular degeneration in both sheep and cattle (Willman *et al*, 1945; Blaxter and Sharman, 1953). This syndrome has, however, not been reported under Indian conditions of management. This is not surprising since wheat bran, oil cakes and gram, which are all rich sources of vitamin E are usually fed to our cattle.

Of all the vitamins, vitamin A is the most important at least under Indian conditions. From practically every state in India, vitamin A deficiency symptoms like night blindness and blindness in calves have been reported, particularly in urban cattle. There is good reason to believe that pneumonia in young calves, white scour and certain types of sterility occur readily in animals whose normal resistance against infections has been lowered through a deficiency of vitamin A. This widespread occurrence of vitamin A deficiency can be easily understood if one remembers that in this country an abundance of green feeds is found for only 3 months in the year i.e., during the monsoon. 30 micrograms of carotene per kg. body weight are required daily by the ruminants in order to prevent night blindness, whereas, double this quantity is needed for maintaining a normal level of vitamin A in the blood. Weight for weight this quantity is 3-4 times that required in rats or men. This high requirement in ruminants is due to the fact that only 30-40 per cent of feed carotene can be absorbed from their alimentary canal. Preformed vitamin A, on the other hand, can be digested nearly completely so that its requirement is only 7-9 micrograms per kg. of body weight. Under practical conditions of livestock feeding, preformed vitamin A is seldom administered.

Young growing grasses contain a large amount of carotene, its content being of the order of 8 to 12 mg. per lb. of such forages. In other words, 4 lb. of such feeding stuff will supply the daily need of carotene in a non-producing cow of 1000 lb. body weight. Towards the end of the monsoon, when the grasses are in flower the value is reduced to about 2 mg. per lb. As during the monsoon season, an adult animal can easily consume 30 lb. or more of green fodder daily through grazing, it can be seen that it does not only get its optimum quota of carotene but in addition can store some vitamin A. Under urban conditions, however, ample grazing is not always practicable, so that storage of vitamin A in city cattle is low even during this season. After the rains have stopped, the carotene content of grasses diminishes rapidly with maturity and grazing also becomes scanty. Under these conditions, unless winter crops like berseem, lucerne etc., raised through irrigation, are fed, the body reserve of vitamin A gets exhausted and the animal starts showing symptoms of nightblindness during the later part of the winter season or during the summer when practically no grazing is available. Hays and straws and concentrates which form the bulk of the ration in a stall-fed animal contain negligible quantities of carotene. During years of scanty rainfall, more severe symptoms of deficiency like blindness occur as were seen in the cattle of Rajasthan during the famine year of 1938-39 (Fernandes, 1940). Codliver or shark liver oils may be used as preventives in such cases, though their prolonged use is not advocated due to their destructive effect on vitamin E and consequent production of muscular degeneration. In area where irrigation facilities are not available, the best way of preventing vitamin A deficiency is through feeding silage made from young grasses. Green forages when properly ensiled have been found to retain 40-50 per cent of their carotene content even after 2 years storage.

The case of the suckling calf requires greater attention so far as provision of vitamin A is concerned. For the first few weeks of its life the calf cannot convert carotene into vitamin A. Moreover, its requirement at this period is 5-10 times greater per unit of body weight as compared to the adult animals. Fortunately, nature provides for this emergency by supplying plenty of vitamin A in the colostrum, where its content is about 10 times that of ordinary milk. This high value is however, only obtained when atleast 25-30 lb. of good quality green fodder is given daily to the dam during the last 2-3 months of her gestation period. If the calving takes place in late winter or summer months, the vitamin A content of colostrum may not be high due to a sub-adequate intake of carotene during the later part of the gestation period. Calves reared on the colostrum and milk of such dams have been found to be very susceptible to pneumonia and white scour and large mortality figures from such causes have been reported from many farms during these seasons. Administration of vitamin A concentrates to such calves has been found to have good preventive value.

The vitamin A potency of milk is dependant to a great extent off the level of carotene intake by the lactating animal. At least 5-10 times the minimum requirement of carotene need be supplied in order to maintain a potency of 200 IU/100 ml. milk. Feeding more carotene is of no avail in raising the potency to any further extent. During late winter or summer months when green feeds are scarce, the potency may fall to 100 IU or even lower per 100 ml. milk. The beneficial effect of supplying all the year round succulent feeds either as green forages or as good quality silage on the vitamin A potency of milk and its implications on Public Health is thus evident.

THE IMPORTANT ROLE OF RUMINANTS IN INDIAN ECONOMY

From the foregoing it will be apparent that the peculiarities of ruminant mode of nutrition enables animals like cows, buffaloes, goats and sheep to utilise feeds like straws, grasses (fresh or ensiled), oilcakes, brans and husks not only for their maintenance but to convert them into quality foods like milk and meat as well as into wool for human consumption and use. Besides, in India and many other tropical countries, cattle provides main labour for cultivation, transport of goods from rural to urban areas, thrashing and irrigation work. The bulk of the food consumed by them cannot be used by man or even by swine or poultry. They are thus the greatest benefactors to human beings as they render such yeoman service to mankind without competing very much with the latter for their sustenance. Unfortunately, however, they are more often taken for granted and under the present conditions in India, the majority of this class of livestock are allowed to feed for themselves or are kept on straws and a little concentrate hardly sufficient even for their maintenance. The quantitative aspects of their requirement for different nutrients are generally overlooked and the result is that the average cattle in India is of a puny stature with the lowest milk yield in the world. The working capacity of our bullocks leaves also much to be desired. This poor quality has led to the maintenance of a large number of animals to do the work which could have been done by a smaller number of more efficient cattle. This has resulted in less feeds being available per capita and the vicious circle has thus been completed. Under or malnutrition is the greatest single factor in causing the degeneration of Indian farm stock.

In several farms in India, a number of breeds of cattle reared and kept under good management have shown milk yield records of 10,000 pounds or more per lactation. Even under village conditions, nondescript cows, when given balanced rations, have shown 87 per cent increase in milk yield (Patnaik, 1953). The cost of production of a pound of milk has been found in the latter case to be reduced by 35 per cent. This shows that given proper conditions, our cattle can perform much better.

India possesses 159 million of cattle, 45 million of buffaloes, 56 million of goats and 39 million of sheep. The position of feed supply from current available sources falls far short of the requirement if these are to be maintained on balanced rations. It is reckoned that the shortage in the supply of energy is 60 per cent and of protein 75 per cent (Kehar, 1953, 1). It has also been pointed out that the total cultivable land when rationally used can not only yield sufficient food for maintaining both the human and livestock population but can also produce the necessary cash crops (Sen *et al*, 1954). Such an intensive use of land will not only give us sturdier bullocks for work but will also produce sufficient milk to increase the percapita human consumption of this important quality food from 5 ounces to 8 ounces. The nutritive value of milk is so well known that the resultant benefit which will accrue from this extra available milk for national health need hardly be dilated upon.

In achieving the best results out of our animals, particularly the cattle, greater amount of research work in the field of animal nutrition is essential. For this, collaborative work of scientists from different fields is absolutely necessary. The physiologist and biochemist have long been working as a team in studying the ruminants' need for various nutrients and how these are utilised by them for maintenance and production. They have been helped in this work by the chemists and physicists who have provided basic tools for carrying out such studies. The synthetic vitamins, isotopes, spectrophotometers among many other things have opened new vistas for nutrition research. A good deal of information has been accumulated, even so limitations of present knowldge are felt too well by any nutrition worker. We should like to have the help of the chemists to devise simple nitrogenous compounds which in the rumen will liberate ammonia at a sufficiently slow rate so as to be utilised fully by cellulose splitting bacteria. It is hoped that microbiologists will be able to classify the different bacteria and protozoa of the rumen and to find out their metabolic behaviour, so that it may be posssible later on to control the symbiosis to the greatest advantage to the ruminant host. The interrelationship between agriculture and nutrition is obvious. The nutritive value of a large number of grasses and legumes has been worked out but the role played by different fertilisers in improving the nutritive value or increaesing the yield of nutrients per acre remains largely to be worked out. The utility of rotational grazing, the part played by nitrogenous constitutents of animals droppings in increasing the fertility of the soil, the development of different types of pastures suitable for various soil-weather conditions—these are some of the questions which still remain to be answered. Solution of these and many other problems in India lies in the future collaboration between the nutrition workers, soil chemists and agronomists. A beginning has been made in India to study the behaviour of cattle under different climatic conditions and geneticists can be of great help in finding and developing breeds which can thrive better in the humid warm regions of our country. Many other nutritional problems remain to be tackled in order to make our cattle population of greater asset for improving our social economy and national health.

The greatest stimulus for improving the productive capacity of our livestock can, however, be given if and when it can be demonstrated to the stock owner that livestock farming is an economic proposition and that the investments in better management through proper feeding are likely to yield handsome dividend. A cooperative society in the Kaira district of Gujrat has given the lead in this direction. The society arranges to supply concentrates at reasonable rates to the livestock owners of the area and in return buys milk from the members at fixed rate. The milk is processed and then transported to Aarey Colony, Bombay for sale. Starting in 1948 with a daily supply of only 6 maunds it now sends over 700 maunds daily today. Even after this the Society is having a big surplus of milk which has necessitated the establishment of a creamary and dried milk factory at Anand. Production of milk in that area has now become a source of substantial additional income for the farmer. Given proper facilities for collection, processing and transport of the perishable animal products like milk and meat, this picture can be reproduced in many other regions of India. Milk colonies similar to that of Aarey in Bombay or Harringhatta in West Bengal are being established by Government agencies near several other big cities, but private ventures like that at Kaira can also accomplish much for bettering the condition of farmers in rural areas. The whole problem is integrated with the general development programme of the country and it is gratifying to find that the necessity for the improvement of our livestock has been fully recognised in our Five Year Plans. In the fulfilment of the target of the plan, the animal nutrition workers will have to play an important role. Training of a large number of personnel in physiology in general and animal nutrition in particular will be essential to provide sufficient number of workers for this task.

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SECTION OF PSYCHOLOGY AND EDUCATIONAL SCIENCES

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PRESIDENTIAL ADDRESS

PLANNING PSYCHOLOGICAL RESEARCH IN INDIA

Permit me first to express my deep gratitude to you all for the honour that you have done me by electing me the President of the Section of Psychology and Educational Sciences, Indian Science Congress Association. I shall utilize this opportunity for discussing the problem of planning psychological research in India—a problem, which I believe, is of paramount importance for the future of the subject to which we all owe our allegiance. I would, however, like to ask in advance forgiveness from my esteemed colleagues for any observations that might appear unpalatable, and yet are necessary for the healthy development of our science in this country .In the interest of self-correction and consequent advancement in the years to come, it is desirable to have an occasional stock-taking of "the little done, the undone vast."

In comparison to other countries psychology in India has not attained the place and role that it should enjoy. The development of psychology as a science as well as a profession and a technology has been rather meagre. People are becoming more and more anxious about the ability of psychologists to help solve the diverse problems arising from technological advances and from the swift social transitions they leave in their wake. Consequently, the demand for the development of psychology in all its three aspects—scientific, technological, and professional has become very great. The development in the different aspects, however, must take place simultaneously for Bingham[3] rightly points out, "Psychology is one. Practitioners, technologists, scientists, all must be psychologists even though some strive primarily to further the aims of the science, while those in the fields of application work serve other aims, be they educational, commercial, social, governmental or the aims of an individual client in search of the fullest realization of his potentialities". And, instances are many where psychologists have won distinction in all these aspects. The contributions of Janet, Pieron and his colleagues in France, Galton and C. S. Myers in England, Cattell, Thorndike, Lightner Witmer and Munsterberg in America, Edouard Claparède in Switzerland, Jaederholm in Scandinavia, Ponzo and Gemelli in Italy, Michotte in Belgium, Ebbinghaus, Lippman and Stern in Germany, Ishahira in Japan and a host of others clearly indicate the concomitant development in the different aspects of psychology.

The slow development of psychology in India can be attributed to the rather late and unplanned growth of the autonomous department of psychology in the various universities. Departments of psychology in some universities even today are under the dominance of teachers of philosophy. Besides, there are not very many *qualified* psychologists in this country to cope with the tremendous amount of work that needs to be done nor are there adequate facilities for utilizing effectively whatever talents we have. Psychology has not been utilized by government, education, industry and other agencies to the extent it has been in most western countries and few positions exist for psychologists outside the universities. But by far the most important factor responsible for this rather unfortunate position appears to be, what may be termed, the paucity of psychological research in this country.

It is, therefore, not unnatural to sense in today's intellectual atmosphere of this country the urgent need for more adequate research in the field of psychology. But before we consider some of the lines along which fruitful research work should be done, it may be worthwhile to understand the implications of research in the field of psychology and the various criteria for its proper appraisal.

II

It may be well to begin our discussion of what does constitute research by clearing up certain prevalent misconceptions about it. Bacon, for instance, held that by recording and tabulating all possible observations and experiments, the relations would emerge almost automatically. And following Bacon, many investigators regarded scientific research as consisting in mere collection of enough data with the use of new gadgets and apparatus. This view, however, is no longer acceptable today. As Hutchins R. M.[11] writes: "Research in the sense of gathering data for the sake of gathering them has no place in a university . . . . . Research in the sense of the development, elaboration and refinement of principles, together with the collection and use of empirical materials to aid in these processes, is one of the highest activities of a university and one in which all its professors should be engaged."

Another erroneous notion about scientific research is found in the tendency in some areas of psychology to work out elaborate classifications, with the implication that if the behaviour of an individual can only be properly pigeonholed in some static system, then further analysis of a functional nature would be unimportant. Obviously, Karl Pearson's emphasis on classification as a major pursuit of science undoubtedly did a great deal to establish this misconception. On a careful review of the literature in the fields of personality and clinical psychology, it would, however, be sufficiently clear how specialists in these areas are struggling to free themselves from older classificatory systems.

Research, no doubt, leads to advancement of knowledge. But it should be borne in mind that advancement of knowledge is not necessarily the same thing as discovery of new knowledge or originality of any of the three kinds, viz., originality of theory or hypothesis, originality of method or technique, and originality of data, for "repeat" studies are valuable in advancing knowledge by demonstrating the validity or otherwise of the previous theory, method, or results. The process of consolidation of knowledge is as much a part of the research process as the process of discovery. Hence, as Raj Narain[20] also feels it would be wrong to assert that all research is original. Smith H. L.[22] pertinently observes:

> "One of the common errors in defining research results from the general intimation that all research must concern itself with something entirely new . . . . The bulk of the research carried on today has as its purpose the improvement of the old—whether the term "old" be applied to objects, principles, or methods of procedure."

Jahoda *et al*,[12] in fact, go a step forward in saying that "research is oriented toward seeking answers ; it may or may not find them. More often than not social research results in the raising of new questions or the reformulation of old ones". Smith[22] also writes:

> In fact that research does not always result in the establishment of a partial or complete truth should not be construed to mean that such endeavours fall short of what research purports to accomplish. The mere fact that the investigation has been made is a contribution to the field.

What then is research? In the words of Woody[25], we may affirm:

> Research is a "careful or critical inquiry or examination in seeking facts or principles ; a diligent investigation to ascertain something", according to *Webster's New International Dictionary*. This definition makes clear the fact that research is not merely a search for truth, but a prolonged, intensive, purposeful search. In the last analysis, research per se constitutes a method for the discovery of truth which is really a method of critical thinking. It comprises defining and redefining problems ; formulating hypotheses or suggested solutions ; collecting, organizing, and evaluating data ; making deductions and reaching conclusions ; and, at last, carefully testing the conclusions to determine whether they fit the formulating hypotheses.

Jahoda *et al*[12] also emphatically point out that "the purpose of research is to discover answers to meaningful questions through the application of scientific procedures."

In short, it can be said that research involves three major steps: (a) discovery of a problem, (b) formulation of hypothesis, and (c) application of scientific method for the verification of hypothesis. It may be further borne in mind, as Cantril *et al*[6] have also pointed out, that scientific enquiry and scientific method should not be confused with investigations, limited solely to a so-called quantitative approach, for many significant problems for which quantitative data are not available are lost sight of this way.

A distinction is often made between basic and applied research. Many psychologists sometimes seem to define basic research as "what I want to do, whatever that is, and whenever the mood strikes me", whereas applied research means "research which someone else wants me to do, with his own practical purposes in mind". In other words, there is an indication of an antithesis between pure and applied research. This view, however, is not acceptable. Melton A. W[16] says: "By basic research I mean search that is conducted in such a way that the scope of applicability of the result extends beyond the range of the particular set of circumstances involved in the investigation, i.e., the prediction and control of natural phenomena are somehow greater than that involved in predicting what would happen in an exact replication of the experiment just completed". There is no antithesis between basic and applied research. A sound basic research policy, in fact, is the foundation of later developments on the applied side, and basic research is often stimulated by applied research done mainly because of practical needs. Bray[4] also points out, "As a former student of auditory processes, ... I can testify that much of the information which guided my research originally came from medical men concerned with deafness and from acoustical engineers concerned with communication. Much of the information, in other words, required for basic research came from men whose motivation was application. On the other hand, the trouble with the treatment of deafness and the development of good communication equipment was frequently the lack of a solid theory of hearing. Thus there is no genuine antithesis between basic and applied research". Katona[14] also is in agreement with this view.

III

If we are to plan intelligently, the future research programmes that will advance psychology in this country, it is particularly timely now to make a critical examination of what has been accomplished, what the major gaps in knowledge are, and where further investigation is necessary. And for this, we need to evolve certain criteria in terms of which proper evaluation of the psychological work can be done. Wolfle *et al*[24] have mentioned eight criteria for this purpose. The first four criteria deal with the formulation of hypotheses and their organization into scientific theories. In other words, they deal with the conceptual aspects of a research area. The last four criteria, on the other hand, deal with the experimental aspects. Those eight criteria are as follows:

Criterion 1. To what extent have first-hand observations which lead to testable hypotheses been made?

. . . . . . In a relatively undeveloped science—and psychology is certainly that—it is probably always safer and practically always more fruitful to keep hypotheses fairly closely tied to actual observation of the types of behaviour involved. The danger is that as one gets away from hypotheses that are closely tied to such observations, they will become vague generalizations or arbitrary assertions that are not in a form to be tested . . . . . .

Criterion 2. What is the stage of theory development?

. . . . . . theories are an important aid in focussing research. . . . The development of as inclusive and as rigorous theories as possible should, therefore, be one of the primary objectives of investigators working in any research area.

Criterion 3. Are the problems which have been formulated—as well as the theories—stated in scientific terms?

. . . . . . Whether a problem is precisely formulated on the first attempt or on a later one, it must eventually be so stated as to show the following characteristics:

(a) It describes a replicable situation.
Questions about unique events have no place in research.

(b) Value terms must be excluded.

. . . .

(c) The variables must be defined.

Criterion 4. Do the formulated concepts, theories, and problems cover the area?

. . . . . . An area is defined by a formulated set of problems. Thus its boundaries will shift as knowledge accumulates, new relationships are seen, and research interests change. At any given time, however, an area can be prescribed, at least approximately. Concerning that area one can ask, "How well do the problems which have been formulated cover this area?"

Criterion 5. How adequately can controlled observations of the variables involved in this area be made?

. . . . . . The most powerful procedure for making such observations is the method of experimentation. . . . But there are situations and fields of study in which experiments are difficult or impossible. . . . If experimentation is impossible, other methods of making controlled observations are essential. In either case, one criterion of the level of development of a research area is the extent to which controlled observations of the variables can be made.

Criterion 6. What is the level of mensuration in the field?

The progress of research in any area of psychology depends upon how well the variables involved can be measured . . . . The simplest and most elementary kind of measurement consists of being able to segregate a collection of events into separate categories. If the events can be so segregated we can count the number in category and we have what is sometimes called a nominal scale . . . . A second level of measurement develops when the classes of events can be put into rank-order arrangement so that various observers agree that D is greater than C, and E is greater than D. This type of scale is called an ordinal scale . . . . A third level of development is attained when the scale separations of the various elements are made to equal each other so that D is not only greater than C, and E is greater than D, but the difference between C and D is the same as the difference between D and E. This type of measurement is an extensive scale

These three kinds of scales have been listed in order of the increasing amount of knowledge which their construction requires.

Criterion 7. How detailed is the knowledge of interaction among the variables?

To a considerable extent, this criterion depends upon the fifth and sixth criteria—the accuracy of control and measurement of the variables involved. If the variables can be scaled and manipulated precisely, detailed knowledge of their interaction is merely a question of conducting an adequate number of more or less routine fact-finding studies.

Criterion 8. How well coordinated is research in the area?

. . . . . . The final criterion of the stage of development of an area is, therefore, the extent to which research in that area is coordinated in terms of the, units of measurement, the methods, the particular instruments, and the conceptual background employed . . . .

IV

We may now proceed to make a critical examination of the research work done in this country in terms of the eight criteria for appraising psychological research mentioned above. It will not, however, be either feasible or necessary to catalogue here the volume of entire research work done in this country. Those who want to get acquainted with the progress of research work in this country may read some of the reports on psychological research in India. For instance, Bose, G.[4] wrote a paper in 1938 "Progress of Psychology in India during the past twenty-five years". Another very useful article available on this is that of Mitra, S. C.[18] A large volume of work done in the field of Social Psychology is to be found in Murphy's American publication.[19] Barnette[1] has given an adequate summary of research and developments in the area of psychological testing in India. Some of the issues of the "Psychology News Bulletin" (Issued from Psychology Division ATIRA, Ahmedabad) give us news of current research in the different fields of Psychology.

From the reports mentioned above, it will appear that during the brief period of its existence, notwithstanding the political and financial limitations under which psychology had to grow, the progress in the various fields of psychology has been considerable and the contributions of Indian psychologists to the advancement of knowledge and solution of practical problems of life have received due recognition both at home and abroad. Psychology is rapidly gaining popularity all over the country and the Central and State Governments as also the Universities have awakened to the need of establishing centres of research and service.

It is, no doubt, true that psychology has advanced considerably in this country during the past few years. But on a critical examination of the research done in the different fields of this science, it will be clear that the present position of research in psychology is still not very encouraging. There is no broad plan for basic research in psychology. Further, the urgency of practical needs often tempts us or even compels us to extend practice far beyond scientific knowledge. At the same time, it is evident in terms of the urgency that one can no longer rely solely upon isolated investigations. It is, therefore, necessary that a good deal of research in the various areas of psychology be done on a planned basis and at an accelerated rate.

As it may not be possible to do full justice to all the fields of psychology within the compass of this address, I shall confine myself for the present to some of the important ones only.

A. *Psychological Tests.* Psychological test research had its beginning in this country with the pioneer work of Rice[21] on 'A Hindustani—Binet performance scale' which was begun in 1922. Since then, research on psychological tests has advanced considerably. Barnette's article[1] as also notes on psychometrics in the "Psychology News Bulletin" (April 1955) give us an adequate idea about the progress in this area. Three lines of work are now evident: (*a*) psychological testing for school use—intelligence, achievement, aptitude, (*b*) studies with applied problems—such as industrial fatigue, research on tests for worker selection, etc., and (*c*) clinical and personality tests taking the form of a preoccupation with the Rorschach, T.A.T., W.A.T., Horn Hellersberg test and several personality inventories.

But inspite of the progress that we have made, it is strongly felt that we need very much to bring out in the next five years different sorts of tests suitable for different purposes. At present, we don't have enough of standardized tests on the basis of which we should be able to make correct predictions and control human behaviour. But Psychology as a technology has to undertake the task of finding ways of predicting and controlling behaviour. It is called upon to help in achieving the aims of industry, of education, of mental hygiene, of commerce, of government etc. We, therefore, need doing an adequately planned and centralized research in this field on a large-scale. Some of the problems on which useful research work should be done are:

(*a*) Study of a selected number of civil service positions, with regard to actual duties performed, and determination of opportunities and of possible lines of promotion in the selected positions.
(*b*) Study of such factors as experience in governmental and industrial jobs not measured by tests hitherto.
(*c*) Development of a guidance card which will enable the applicant to analyse opportunities in relation to his qualifications.
(*d*) Construction of objective tests for reforming the present system of examination.
(*e*) Study of the problem relating to the extent to which eligibility for one post signifies ability to fill other posts.
(*f*) Establishment of standards for various purposes for the entire nation, making test scores more meaningful to placement officers.

B. *Guidance and Personnel Work.* This is another area in which substantial amount of research should be completed every year in various universities and other centres of research engaged in this type of work. Some of the important problems for investigation are those relating to growth and development of the individual, social and cultural factors affecting his behaviour, interest and interest inventories, projective and sociometric techniques, reading and speech deficiencies and remedial practices, organization of guidance services in schools and colleges, techniques used in counseling duties, qualifications and training of counsellors, importance of group methods in guidance, personnel practices—business, industry, civil and institutional, juvenile delinquency etc.

C. *Mental Health.* The problem of mental health is rather neglected in our country. And the magnitude of the mental health problem is not to be measured by counting the number of people now in mental hospitals, for we don't have very many such hospitals in our country. Besides those who are institutionalized, there are many others considered relatively normal who nonetheless have severe and crippling emotional problems. There are delinquents, alchoholics and those who are accident-prone. There are people who do live normally and work regularly but whose happiness and effectiveness are hobbled by curable psychological difficulties. Mental disorders are human disorders and we can understand them adequately only when we understand the natural laws of human behaviour. Research that helps us understand the human being will benefit not only the mentally ill, but also the potentially ill and the millions of people who now live because of emotional problems, far below their best level of effectiveness.

D. *Human Engineering.* As Warren N. D. points out,[23] "Broadly defined, human engineering is a phase of engineering which applies knowledge of human factors to design of machines—or of products. It is broader than, and includes the fields of engineering psychology, biomechanics, applied experimental psychology, and others". In this field also, we are required to do a lot of research work. Whenever there is a human link in a machine, the errors of the machine are amplified by human errors. In order to reduce such errors, we should work with a view to discover and to develop principles and techniques of engineering psychology for application in the design and operation of man-machine systems, man-operated gears, and instruments. This way, we may be able to ensure maximum use of people working in the industry, and serving in the armed force. Thus, we need doing research on sensory capacity for team efforts, stress, accidents—in fact the whole area of applied experimental psychology.

E. *Psychological Research in problems relating to Armed Services.* At the beginning of World War II, psychologists met with considerable initial resistance when talking with the army people about the use of psychology in the Armed Services. Gradually, as the programmes of research in selection, classification, training and human engineering began to achieve solid and demonstrated success, the military realized the importance of psychological research. And today, we find that in the United States the Army, Navy, and Air Force have several project areas of research. For instance, Finch G.[9] writes:

> "The Air Force has one or more active projects in each of the following:
>
> Detection, recognition, and interpretation of signals, objects, and speech.
>
> Psychomotor factors in personnel selection.
>
> Systematic psychophysical analysis in the planning, development, and evaluation of weapons, countermeasures, and their equipment.
>
> Psychophysical systems research.
>
> Flying safety research.
>
> Ground safety research.
>
> Basic intellectual traits.
>
> Basic personality variables.
>
> Initial screening procedures for recruits and draftees.
>
> Identification and selection of leaders.
>
> Classification into enlisted specialities.
>
> Classification procedures for officer personnel.
>
> Analysis of the psychological requirements of job.
>
> Criteria of performance.
>
> Work modification.
>
> Military manpower requirements.
>
> Military management.
>
> Strategic planning and intelligence.
>
> Psychological warfare.
>
> Techniques for the modification of knowledge and skills.
>
> Research on the modification of personality characteristics.
>
> Emotional and effective methods of mass instruction.
>
> Principles and procedures for selecting the content for military training programs.
>
> Training for perceptual and sensory functions.
>
> Conditions of efficient learning and retention of psychomotor skills.
>
> Training devices.

In India, the Psychological Research Wing of the Defence Science Organisation, Ministry of Defence, Government of India, is undoubtedly doing valuable research in the construction and standardization of tests for use in the Armed Services. But for an adequate development of research in this field, it will be necessary for the psychologists serving in the Psychological Research Wing to hold conferences with psychologists working in the universities and work on certain problems in collaboration with them. Thus Hill, Charles W.[10] also writes: "Psychological research is firmly established in the military services. However, in order to maintain this position, the military psychologist must continue to produce sound and stable answers to military problems. This goal requires the support and cooperation of all psychologists, wherever they may be working. The problems are science-wide, and the research and its results are beneficial to the whole science and profession of psychology. It, therefore, behooves all psychologists to keep abreast of this research within the armed services and to give it their full cooperation and support".

F. *Research on International Conferences*. In 1947, the General Conference of UNESCO passed a resolution emphasizing the practical need for better knowledge about international conferences. It called upon social scientists of various international agencies to devote themselves to the study of problems relating to international conferences. A small group of social scientists discussed fully what features of international conferences should be studied. Cartwright D.[7] mentions the following major headings as an outline of possible research . . . . arrived at as a result of several deliberations held by the social scientists :—

1. Problems of Administrative management : Physical and social environment ; Internal structure of the Conference. Substantive preparation.
2. Conduct of Discussion : Leadership (chairman and secretariat) ; Procedural problems.
3. Intra-Conference Communication : Language and semantics ; Non-verbal communication ; Order and content of speeches ; Documentary drafting.
4. Cultural, Ideological and Psychological factors : Impact of differences of ideology ; Personality *v.* national and ideological patterns.
5. Phenomena of Official Representation ; Differences in instructions and their interpretation. Impact of differences in power of member organizations.
6. Influence of Publicity : Effect of publicity on participants' readiness to compromise ; Effect of publicity on formality of discussion ; Effect of publicity on content of discussion.

The psychologists in India should seriously think of collaborating in research projects on some of the topics mentioned above.

V

From what has been pointed out before, it is obvious that the position of psychological research in India is not a very happy one. The Indian psychologists, therefore, are required to do a good deal of research work in the different fields of psychology in the next few years to come. And fortunately for us public awareness of psychology and its importance is also increasing. People appear willing to accept the result of psychological researches. It has consequently, become all the more necessary for us to do a lot of effective research work in this country. Modern society needs psychological help, and so, psychologists must render such help as is required of them.

A number of research problems in the various fields of psychology have already been indicated in the previous section. The question before us now is : How should we plan and conduct research in the different areas so that fruitful results may be made available? As we know, no broad plan for either basic or applied research exists on an All-India basis.

Whatever progress has been made, is largely the product of the un-coordinated efforts of the individual researchers in the different fields of psychology. Individual psychologists have been doing research work independent of each other with the result that we don't find any coordination in their research programmes. There has been a good deal of duplication of work in certain areas and at the same time some areas have been relatively left unexplored. It has often happened that psychologists in different parts of the country have been working on the same or similar problems simultaneously, unknown to each other. Obviously, the progress of psychological research in this country has suffered a great deal for want of proper communication, coordination and cooperation between research workers. Cooperation in coordinated planning of research on a country-wide basis is, therefore, the prime need of the hour.

And so, we need to attack the different fields of psychology on a well-planned and coordinated basis by a team of individual researchers and institutions. In other words, there is an urgent need in this country for the development of a large-scale group research. Participation in group research or team work, no doubt, means some loss of independence to the individual researchers. But in the larger interest of the development of science as also the fulfilment of the needs of the people in the country, it is necessary that we do this. It is often pointed out that there is an antithesis between organized group research and individual research. But on a careful examination of the facts, it will be clear that there is no genuine conflict between the two—one actually supplements the other. Thus, as Lanier, L. H.[15] while discussing the question of group vs. individual research, also remarks: "Our individualistic research has been sporadic and unnecessarily idiosyncratic in nature. We have too many old lots of incommensurable data. For all of its complications, group research affords the opportunity of building sound empirical foundations in fields where contradictory results and random speculation have been our main stock in trade."

But as we proceed to organize group research on a large-scale, we are faced with a number of problems. The most important problem is that of the establishment of some organization for this purpose, which is discussed in detail later on. But apart from this, there are several other factors mentioned by Miller, Delbert C.[17] which very much affect research design for group research. These include: restrictions imposed on the individual researcher, the demand of time schedule, personal wants of researcher, opportunity for each researcher to apply his talents to a project, the accumulation of empirical and theoretical knowledge etc. These factors create problems as well as opportunities for research. As Miller[17] writes: "Access to the research field and cooperation within it opens a new wealth of social data. A long standing weakness of social science research has been the inability to get enough individual cases or organizational units so that relationship could be validated through replication. This is possible in large-scale group research. These opportunities can be capitalized, but only as the social processes of group research are marshalled" (p. 390).

In the course of the development of a social science, a stage is often reached when it can no longer grow by remaining confined to its own limited territory. People belonging to one discipline are called upon to confer with experts of other disciplines and make efforts towards the integration of several disciplines. For instance, in recent years a definite demand towards the integration of such disciplines as psychology, anthropology and sociology can be easily discerned. There are numerous problems of social significance which need for their adequate solution the cooperation of social scientists of different categories. Let us for instance take the problems of tribal people in the different parts of the country. Their problems can be understood only if we organize group studies by a team of research workers consisting of psychologists, sociologists, and anthropologists. The problem of rehabilitating the refugees is another pressing national problem which demands adequate interdisciplinary research.

In short, it can be said that we need doing in India today a good deal of multidisciplinary research[3] or what is also called corporate research.[13] By multidisciplinary research is meant the integrated activity of specialists from a number of fields working together on a common problem. This kind of research promises more fruitful results in attacking a number of social problems. The complexity of this type of research depends upon such factors as the number of people doing research, the kind of action involved in research process and the number of disciplines involved in research.

Again, there are several problems (e.g. social prejudice, tensions of various kinds etc.) which are of great concern to various nations. And, the more adequate solutions to such problems can be arrived at only by planning and conducting research work in those areas on an international level. Consequently, there is a need today for cooperative international research organization so that social scientists from different countries could plan and conduct research on problems of common concern. Further, it is found that some studies on social issues are made in one nation, but it is not known whether the conclusions reached can be truly applicable in other nations as well because of cultural differences. It is, therefore, necessary that between-nation comparative studies be done on a large-scale. In other words, we must conduct what is called "cross-national research", if we want to find out the extent to which principles discovered in one culture or sub-culture can be extended to other cultures.

By cross-national research Duijker and Rokkan[8] mean "research undertaken for comparative purposes on the same categories of data across several different national populations or equivalent sections of different national populations". The principal types of comparative cross-national research discussed by them are :

I. "Documentary" studies : comparative analyses of characteristics and relationships in already existing records and materials.

II. "Current Statistics" studies : comparative analyses made possible through increased standardization of data collection and classification procedures in regularly operating statistical agencies and other organizations for the registration of social facts.

III. "Field and laboratory" studies : analyses of data specifically collected and classified for the comparative purposes in mind, whether through direct observation, interviewing, test administration, field experiments, or laboratory experiments.

Of the three types of cross-national research mentioned above, it is the last one dealing with field and laboratory studies that is likely to expand considerably with the greater development of international cooperation in the social and behavioural sciences. As Duijker and Rokkan write[8] : "Comparative sample enquiries, opinion polls, attitude surveys, ecological researches and community studies, organizational investigations, group experiments, and psychological testing programmes across national boundaries are likely to take on increasing importance over the next decade. Cross-national research of this kind requires direct contact with the national populations through field work, test administration or laboratory experiments, and will depend on organizational arrangements very different from those involved in "documentary" and "current statistics studies". In this context, mention may be made of one such study by the social scientists from seven Northwestern European countries who organized themselves into 'The Organization for Comparative Social Research'. If research is to advance in India, it is necessary that psychologists and other social scientists of this country also undertake some cross-national research project in collaboration with the social scientists of other countries.

VI

The foregoing discussion, it may be hoped, has succeeded in bringing to the fore some of the lines along which fruitful psychological research should be done in India. The urgency for the development of a large-scale group research has been amply focussed. The importance of the multidisciplinary research as also the cross-national research has been adequately emphasized. Now, if the plan is to succeed, certain lines of action need be suggested. The details of the various plans will have to be worked out. In other words, we have got to indicate the ways and means by which planned and coordinated psychological research can be stimulated in this country.

Obviously, the entire process of such research splits up into two parts: (a) chalking out of plans for large-scale integrated group research for different purposes and (b) putting the plans into operation. These two aspects may now be considered individually.

With regard to planning, the most pertinent question that arises is: Who shall chalk out the programmes of research? For this, it may be suggested that a Psychological Research Development Board may be established at the instance of, either, the Section of Psychology and Educational Sciences, Indian Science Congress, or, the Indian Psychological Association. This Board shall be composed of reputed psychologists of the country working in different universities and centres of research. Its functions shall be: (a) to plan research programmes in the different fields of psychology, (b) to promote intra and interdisciplinary coordination of research interests and activities, (c) to organize and participate in international research programmes, and (d) to sponsor research bulletins or monograph particularly on the evaluation of methodology and theory in different fields of psychology. Such a Board should get due recognition from all centres of psychological research as well as from the government and should act as the Advisory Board on any major research programme of national or international importance.

But, how shall the programmes of research be implemented? This brings us to the discussion of the second point mentioned above, for which, the following suggestions are offered:

The departments of psychology in the different universities should develop a five-year plan for research. Each department may select one or more areas of research, depending upon the number of adequately qualified psychologists and research facilities available there and conduct a number of joint studies which may round out the pictures in those areas, thus constituting a solid advance and consolidation of research work in the area or areas selected.

The various Institutes of Psychological Research and Service, Bureaus of Educational and Vocational Guidance Mental Hospitals, Psychological Research Wing of the Defence Science Organization under the Ministry of Defence, Government of India, and other centres of psychological research in the country can also undertake certain programmes of research and thus make a definite contribution to the development of research work in the country.

But with the limited resources and facilities available at the different centres of research mentioned above, it cannot be expected that psychological research in this country will advance with as rapid a pace as it should. The main difficulty, as we know, is the problem of finance. However good our programmes may be, it will be difficult, nay impossible, to implement them adequately in the absence of funds. The Central and State Governments, therefore, should help the development of psychological research in this country by making liberal grants for this purpose.

It is time that the Central Government realized the importance of an early establishment of a National Institute of Psychology in this country with a well-equipped laboratory and specialists from the various fields of social sciences on its staff. The major functions of this Institute shall be (a) to conduct psychological research on a country-wide basis on such problems as the national standardizations for various psychological tests, investigations into the causes of social prejudice, national and international tensions etc., and (b) to train psychologists for different types of professional activities.

In closing, I may say that the time has arrived when we, psychologists, organize ourselves and make earnest endeavours to usher in an era of all round development in the different aspects of psychology in this country, for the society which supports us today may repudiate us some day if we fail to act upto its expectations.

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SECTION OF ENGINEERING AND METALLURGY

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PRESIDENTIAL ADDRESS

TRENDS IN ENGINEERING EDUCATION & RESEARCH

I must first express my sincere thanks to you all for electing me to the office of the President of the Engineering and Metallurgy Section of the Indian Science Congress for this session. Incidentally I may mention that it is a matter of satisfaction to note that the theoretical approach to engineering education in India has gained recognition by the comity of engineers and metallurgists as evinced by my election. This is an welcome orientation in the outlook, since the "academic engineer", as already expressed by one of my predecessors, is necessarily preoccupied more with "principles" ; he is more concerned in trying to keep pace with the progress in other countries both in the field of curriculum of engineering studies and in the field of research and developmental activities in the branch of his choice.

During the pre-independence days, for various considerations, more importance was placed on the training up of "practical engineers" than on the fundamental trainings which would build the solid core needed for developmental work in the field of engineering. In this atmosphere, and against all odds inherent in an alien administration, the University of Calcutta after taking the bold step of initiating post-graduate studies and research in scientific subjects in 1914, followed up with the establishment of the departments of Applied Physics and Applied Chemistry soon after the first World War. The department of Applied Physics was established exclusively for the development of technological instruction and research with special reference to electro-technology, applied thermodynamics and standardisation of instruments. Unfortunately, even after so many years, the average man appears to have very little comprehension regarding the true import and scope of Applied Physics. As ably pointed out by my revered Professor, late Dr. P. N. Ghosh, "there has been a very interesting trend in Applied Physics by which great branches of its specialised interests have been appreciated by special groups of applied physicists who call themselves engineers as soon as a systematic method for the application of its principles has been developed in special fields". Thus there are civil engineers, mechanical engineers, electrical engineers, communication engineers, chemical engineers, metallurgists and diverse other groups who are wholly or largely concerned with the application of the principles of physics to practical ends. It would not be too much to state that the economic, social and intellectual influence of applied physics, today, is based upon contributions to knowledge, to industry, and to the art of living,—all these having emanated from the diverse elements which are but manifestations evolved from the knowledge of physics.

In the field of engineering is noticed a tendency for misunderstanding the issue. There is conflict of ideas between the so-called "practical" workers on the one hand and the "scientists" on the other. The practical men have a great source of tradition behind them and the general public has a feeling of conservatism tending to oppose the introduction of new materials and new techniques supplied by the scientists. Nevertheless the trend towards the development of scientific attitude is unmistakably manifest and it is being augmented by force of competition and examples set up by the more enterprising members. It cannot be denied that the engineering industries of recent origin, such as communications, air transportations, etc., have been built upon recent scientific discoveries. Unless continuity of research activities is maintained in these industries their progress is bound to be arrested and a condition of stagnation will prevail.

The attainment of political independence has opened up a new era. All efforts are now being directed towards rapid development in different spheres so as to obtain social and economic security. To secure sound development the Government has launched the successive five year plans. Admittedly anticipation of the future is the key to adequate planning for the best use of our national resources. In this planning for the future the influence of scientific and technological program, both in academic activities and in industrial development, for moulding the economic life of the country must be assessed and suitable steps taken to fit these programs with the objective in our planning.

Progress of human knowledge and the developmental activities of institutions, particularly educational institutions, cannot be static. To quote Francis Bacon: "That which man altereth not for the better, Time, the great Innovator, altereth for the worse". President Killian of M.I.T. has pointed out: "If we are to keep this institution strong, we must constantly adjust its program to new needs and new conditions; we must constantly be seeking to make it a better institution." I feel, the same objective holds for all institutions.

In recent years considerable attention is being given to the consideration of the requirements for technical personnel and for the training of our young engineers to meet the demands of the various national development programs in the industrial and other fields. It will not, therefore, be out of place to consider the question of the educational and research program in engineering in our academic institutions and how best these can be moulded to meet the requirements of the country.

Engineering education began about the middle of the 18th century with unorganised training of apprentices by the early builders of roads in France and by the builders of steam engines in England. From this early beginning has grown the modern system of engineering education. Among these early apprentices were a few who wished to learn more of the 'why' behind the devices and the methods which they were using. These men were the pioneers investigators of much of our engineering phenomena. They borrowed frequently, where available, from the work of the early investigators in physics and chemistry and made their own discoveries. In course of time the rule of thumb or the empiricistic procedure gave place to reasoned one based upon scientific knowledge of nature. To-day fundamental scientific facts provide the basic guiding principle of all engineering education. Thus, in the subject of my specialisation, viz., electrical technology and electrical engineering, are to be found repeatedly manifest, and in most varied manners, the demonstrations of Michael Farady's laws of electro-magnetic induction. The first electrical engineers were all great physicists such as Kelvin, Weber and others. The common electrical units, e.g., volt, ampere, ohm, henry, farad, etc., are named after renowned physicists.

The realisation of the tremendous breadth of opportunity existing to the graduating engineers of the modern scientific age accelerated more and more use of fundamental scientific facts in engineering education. It is necessary, therefore, to find the common denominators needed in the college education so that they will be well prepared for any portion of the engineering field which they choose to enter into. The fundamentals of science obviously constitute this common denominator. Whereas applications in terms of particular devices or methods are almost certain to change, the principles are not changeable. The road of science is the highway along which future engineering education will progress. Type of engineering education prevalent in the past has to undergo a change to meet the demands of the present. Engineering education needs a new look ; it has to be planned carefully so that the graduating engineers are equipped to cope with the problems of tomorrow. Basic knowledge of fundamental principles is a necessary prerequisite to successful practical application. This should not be overlooked by planners of engineering education. New discoveries will usher new eras calling upon the engineers to handle new problems. Engineering education has to keep that in view. Taking the case of electrical engineers it cannot be said what future conditions will confront them. Only the other day the measurement of time and speed was roughly bounded by the milliseconds. At present the time intervals are as short as millimicroseconds. I cannot feel happy about any plan of education for electrical engineers which too much narrows down their respective fields of specialisation. In this connection I may mention that in recent years there has been an unfortunate trend in our engineering and technological institutions to bifurcate completely the basic electrical engineering education into two branches, viz., the electrical engineering course (heavy power) and the communication engineering course (light current). As a result, the tendency has been noticed of depriving the electrical engineering students of getting a sound background of electronics and similarly the communication engineering students of that of a fundamental knowledge of electrical machines and power systems. Are we justified in taking such a step? Do we have any visualisation of the future in electrical engineering practice? In this context the words of well known authorities in electrical engineering education and in electrical engineering industry may be quoted:

"If the scientists can look confidently at the next ten years or so, what does he see? The things that are just ahead range from the indespensable gadgetry of modern living to the fundamental energy generation and conversion processes of modern industry. For one thing, in the next decade we will be completely saturated with electronics. And, although it seems remarkable, the electron—discovered back in 1897—is still a lusty child far from maturity. Tomorrow's electronics not only will be in the office, the factory and the farm but also will perform dozens of functions in the home including cooking. In this next decade, factories will undergo important progress in automatic manufacturing, with electronic technology as the vital key to automation. By the end of this period, automation will have become an absolute necessity. Semiconductors represent the rich relatives in the electron family—rich in promise and potential. Semi-conductors in the form of transistors and similar devices with electronic capabilities will be found everywhere during the next 10 years."

Electronics is already playing its role in the generation and transmission of electric power. Voltage regulation, protective relaying, electronic fault analyzer, telemetering, interconnected system operation, automatic load and frequency control, economic load dispatch—to name only a few —have already become simpler and more reliable with the application of electronics. Microwave relaying and telemetering have already proved their merits and wider scope over carrier relaying.

At the present time industrial organisations are increasingly realising that they must invest in technological progress to meet competition. Many industries realise that new fundamental scientific knowledge represents as important a raw material as the tangible stuff from which products are made. Though the application of science to industry began to receive recognition as far back as 1875, it received little support from industrial leaders. Even at the turn of the century industrial research, as we know it now, was non-existent in progressive countries like U.S.A., U.K. and Germany. Industrial research really began about 1900 in a small way. The earliest growth in industrial research occurred in the industries that actually had been born in the laboratory, or that were directly dependent on new knowledge for their growth. In a survey made by the National Research Council of U.S.A. in 1920, it was found that there were about 300 laboratories which were engaged in industrial research and that about two thirds of all research workers recorded were employed in the electrical, chemical and rubber industries. By 1940 the number of laboratories increased to more than 2000, and the total number of people employed in these laboratories jumped to more than 70,000. The annual expenditure increased sharply to $400 millions. A recent survey in U.S.A. indicate that nearly 3000 companies now maintain industrial research laboratories, and employ over 250,000 people, including well over 100,000 scientists and engineers. During 1956 U.S. industries spent $2·7 billions for research and development.

In our efforts in improving the economic condition of our country a large number of technically qualified men are needed not only for the execution of the jobs but also in the field of industrial research. Industrial research in these expanding developments bears a symbolic relationship to our universities. With advances in technology the industry grows more complex and the educational institutions in the country have to meet new duties. There are new obligations that are falling upon educational systems. Engineering is concerned with both *science* and *art* of utilisation of materials, energy and men. A university by its basic concept is well fitted to the teaching of knowledge, and therefore it should undertake the preparation of the young engineers in the *science*, the *why* of things. An *art* is inherently foreign to the concept of a university. It would seem most logical that the art of engineering should be taught by the engineering employer, by industry. The 'University will teach the fundamental basic science and the industry will teach the art of engineering. It is interesting to mention in this connection the recommendation of the Educational Policies Commission of the National Education Association, U.S.A., that "Industry should undertake more of the task of specific job training than it has in the past assumed, seeking to develop such programmes at a professionally sound level."

The need for imparting an advanced level of engineering education at our institutions has become pressing in our country since independence. So long our chief reliance has been on an undergraduate professional preparation. That system has produced principally a standard of training for professional engineering and technicians job. Time has come for changing the system. An educational institution, as pointed out by the President of A.I.E.E., can be considered analogous to an industry in that it turns out a product. To do so the educational institution has to strive continuously to improve its "product" by readjustments in its methods of production. The events of the last two decades show an astounding acceleration in the advancement of technology. The rate of acceleration seems destined to increase further. Foundations have been laid for future work in new branches of study. The second world war has brought into focus some of the most complex and intricate problems, requiring a thorough understanding of many of the basic sciences. In the field of mechanical engineering, the engineer is now faced with new problems of heat transfer, energy conversion, and fluid mechanics, as a result of the tremendous developments in gas turbines, rockets, jet-propulsion and nuclear engineering. The metallurgist is faced with the problem of finding materials to withstand high temperatures and pressures required by the development of nuclear reactors. Intricate problems associated with the controls in general and control of nuclear reactors in particular present a real challenge to the electrical engineer. New and expanded generating and transmitting systems require that the power engineer be able to project his knowledge beyond the superficial understanding of the present day equipment and system arrangement. The engineer of tomorrow must be equipped adequately to effect this rapid transition. It is time that we break with tradition and eliminate vocational type of courses at the degree level. The scientific training at the undergraduate and post-graduate levels should be reoriented so as to enable the graduating engineer to fit in suitably into the pattern of scientific and engineering developments now envisaged. The universities are no longer to prepare a man to hold a job upon graduation ; their responsibility now is to prepare a man so that he can hold a very good job several years after graduation. If any industry hires a young man and expects him immediately to be able to undertake work which will show a profit, it should go for a technician and not an engineer. The engineering colleges can only help to work out the difficulties inherent in orienting the modern young engineer into an engineering job so that in a relatively small number of years he will be paying a dividend to his employers. Many industrial concerns in the Western countries have gone ahead of the educational institutions in recognising the need for engineers of such higher attainments. Consequently, they have set up training programmes of their own to carry their engineers to more advanced levels than the young graduates fresh from the college. The industry has had to do this because of the inadequacy of the preparation of their engineers in the colleges.

The recent trend in U.S.A. and industrially advanced countries is to stress upon a program in the engineering institutions that is less vocationalised at the undergraduate level and fundamental enough in basic sciences and humanities in order to raise a new breed of engineers more adaptable to their rapidly advancing technology. With our goal for technical advancement and industrialisation time has come to start our planning of engineering education on similar lines.

At present, the universities here and elsewhere are required to undertake research or other activities which are outside the area of uncommitted research and teaching. The importance of such activities cannot be ignored, but the leaders in education feel that these should not be allowed to so warp their total effort that pure research is retarded or diminished.

The best defence against the undermining of basic research is to hold fast to the University ideal of an environment where original investigation and learning go hand in hand, each abetting the other. This specialised function of an educational institution must be recognised and protected.

Today engineering and its sub-division and off shoots are active everywhere from planning, production and distribution to highly creative innovation and research. Activities of engineers run the gamut from relatively routine, but nevertheless important, tasks to those involved in the endless search along the ever widening frontiers of knowledge. Without in any way disparaging the day-to-day practising engineers, the real and vital need is to find and encourage, the relatively small number of high quality creative people to produce the fundamental knowledge, which others can use, and supply the leadership which really determine the character of any profession. It is clear, therefore, that we must put more emphasis on post-graduate education as also on research opportunities for those who have the inclination and ability. This emphasis on fundamental knowledge is logical and natural in the healthy growth of a profession. Unless the supply of fundamental knowledge is constantly replenished, the application becomes necessarily limited. The future of engineering lies in the pursuit of creative ideas. Admittedly this kind of proficiency does not come en masse ; it comes from a handful of men—a quality few.

With the establishment and growth of various forms of highly useful research institutions which have basic research as one of their functions, if not their primary activity, the field of pure research becomes dispersed, and the university and educational institutions are no longer its chief citadel. As many of these research establishments are amply financed and are, therefore, able to attract scholars with higher compensation than available at the universities, the latter become less attractive, resulting in handicapping the education of new talents in science and technology. The apt observation of Ambassador Conant of U.S.A. on this issue is: "The extent that fundamental research is in progress in institutes divorced from teaching, the development of talent is impeded". The education of future scientists and engineers, all right thinking men will agree, flourishes best when it can be conducted in an environment where there is harmonious combination of teaching and research and where the scholars are free to follow their own bent.

In the interest of maintaining the vitality of applied science in industries the specialised functions of the educational institutions have to be recognised. What is desired is an effective liaison between such institutions and industries. On the patterns of this liaison President Killian of M.I.T. remarks: "Both industry and the universities seek new patterns of liaison between the fundamental research activities of the university and the more directly committed research of industry so that cross-fertilisation may be encouraged while recognising and protecting the specialised function of each". He advocates enlarged support to men and institutions and is in favour of de-emphasising the support of projects, so that the research workers in the universities can have greater freedom to be uncommitted to externally imposed objectives. Productivity of research efforts in industrial field will depend largely upon the educational systems which can produce an increased number of talented and creative personnel in accordance with the growing need of the country.

I have been dwelling so long on the need of basic scientific studies and researches in educational institutions, which will find their useful application in engineering fields. With the developments in different fields in engineering, the problems requiring solution have become more and more complex. In most cases the calculations by conventional means are difficult or protracted. These have, in turn, led to the development of different methods and computing aids in the solution of engineering problems. I shall now deal with some of these developments.

ANALOGUE METHODS IN THE SOLUTION OF ENGINEERING PROBLEMS

One of the most striking aspects of recent technological and scientific development has been the increasing use of computing aids of various types to carry out calculations conveniently and quickly. The advantages of this procedure are well illustrated in many engineering problems, where increased project size and complexity make careful analysis at the design stage not only desirable but frequently imperative.

The analysis of problems in engineering design may be complicated by one or more of the following factors:—

(i) Number of variables, even in problems that are basically simple, (e.g. analysis of large networks).

(ii) Presence of non-linearities, and

(iii) necessity for obtaining solutions to many closely similar cases in order to select an optimum design.

In all such cases the use of some form of automatic computation may be necessary. The computing machine may be a digital or analogue type depending on the nature of the problem under consideration.

There are in general four methods of attacking a problem.

I. The empirical method based on a combination of past experience with trial and error. The uncertainty inherent in this approach often causes unnecessarily large factors of safety to be included in the design, and may even lead occasionally to some duplication in manufacturing.

II. The analytical method, in which an attempt is made to deduce logically (i.e. mathematically) the behaviour of the system subject to certain stated assumptions. Because of mathematical difficulties, it may be necessary to make these assumptions so far-reaching that they become misleading: for example, the neglect of saturation in electrical machine analysis may well give results which are considerably different from the actual values as observed on test.

III. The use of an analogue technique, which consists essentially of setting up some form of model (in the broadest sense) of the system being studied, and deducing the behaviour of the actual system from that of the model. In the construction of such a model, assumptions may have to be made, but are likely to be less limiting than with the analytical approach.

The basic difference between the analytical and the analogue methods of approach is that in the former the mathematical relationships existing in the actual system are explicitly formulated, whereas in the latter they are imposed implicitly in the setting up of the analogue.

IV. This method, which combines the features of both the last two, consists of a mathematical analysis in conjunction with the use of an analogue computer. The relationship existing in the actual system are first formulated as equations, and those equations are then solved by means of some form of analogue in which the variables in the equations are represented by physical quantities (for example, a voltage or the movement of a shaft).

In analogue representation, the system being represented is generally referred to as the "parent system," and the means of representation as the "analogue." There are different methods of analogue representation.

1. There are a few cases, where *mechanical analogues* are used to represent electrical parents. For example, the transient stability of a power system may be determined by means of a mechanical assembly of rotating weights and linkages. There are also examples of representation of mechanical systems by small scale physical models, such as wind tunnels or ship testing tanks.

2. Most analogues in common use are electrical in nature, while the parent systems that they represent may be electrical or non-electrical. An *electrical analogue* frequently consists of a flexible electric circuit, provided with means of applying controllable driving voltages and of measuring the response. Thus:

(a) The circuit analogue may represent a parent system that is itself of circuit form, for example, a power system or a control system.

(b) It may represent a parent system which is non-circuit or non-electrical in nature, such as an electrical or thermal field, an electrical machine or a rotating mechanism. For such a representation, an equivalent circuit is derived, the circuit equations of which are analogues to the field or performance equations of the parent systems.

3. For some types of problem (particularly those involving electrical, magnetic, or thermal fields), it may be advantageous to use a *field analogue* rather than a circuit analogue. Such an analogue can be constructed by the use of an electrolytic tank. The physical configurations of the field in the parent is represented by the arrangement of electrodes in a tank of conducting liquid.

4. Where it is not possible to represent the equations of the parent system by a practical equivalent circuit, the solution of these equations can frequently be obtained directly by means of an analogue computer, often referred to as a *differential analyzer,* which may be either electrical or mechanical in nature. Either type consists essentially of a number of proportional, differentiating and integrating elements with means of interconnection. Either type is capable of the accurate solution of ordinary differential equations (including non-linearities and discontinuities), and the approximate solution of certain partial differential equations. The solution is obtained directly without the need for setting up an equivalent circuit.

The mechanical differential analyzer consists basically of a shaft and gear assembly, the variables in the equations to be solved being represented by the angular positions of the shafts.

The electronic differential analyzer operates on the same principle but the shaft and gear assembly of the mechanical differential analyzer is replaced by a flexible electrical circuit in which the mathematical variables are represented as voltages.

The differential analyzer is used for the solution of problems for which no practical equivalent circuit can be formed, and particularly, to obtain the transient response of systems in which non-linearities or discontinuities occur. The only pre-requisite for solution is that the performance of the system to be studied be capable of definition in terms of ordinary differential equations. Hence, the type of problems, whether electrical, mechanical, thermal, acoustical, aerodynamical, is immaterial.

The electronic differential analyzer has been successfully used to study the transient performance of electrical networks and control systems of various types and to solve differential equations associated with the design and performance of electrical apparatus. Small electronic differential analyzers are frequently used for studying the performance of control and regulating systems.

Electrical circuit Analogues :

There are several types of circuit analogues, and the selection of the correct variety to use for the study of any particular problem depends on the type of system to be represented and the type of problem to be studied. These types are:

(a) *The A.C. Network Analyzer*: This is the type of electrical analogue in most general use. It is essentially a highly developed circuit analogue, consisting of a number of adjustable impedance units of inductance, resistance and capacitance capable of being connected together in such a way as to represent a power system or other electrical network, together with voltage sources adjustable in magnitude and phase and comprehensive metering arrangements. Special units such as mutual coupling transformers and variable ratio auto-transformers are also provided for flexibility and range of usefulness.

Such an analyzer when used for power system studies becomes a small scale model of the actual system, the identity of the significant features of the network being preserved and recognisable.

There is also great scope for the use of the A.C. Network Analyzer in the study of non-circuit, and non-electrical problems by means of an equivalent circuit technique.

(b) *Micro-machines and micro-systems*: An interesting development that has occurred during recent years, particularly in France, is the construction of miniature three-phase rotating machines with characteristics that simulate extremely closely those of actual machines. These characteristics, moreover, can be varied easily over a wide range. Such micro-machines can replace the single phase voltage sources used in the conventional a.c. network analyzer, and in conjunction with the various lumped impedance elements will form a dynamic three-phase model of a power system. Such a representation may have distinct advantages for certain types of problem, in particular for problems of transient stability where the relative angular changes of the machines on the system can be directly observed.

(c) *Transient Analyzer*: The A.C. Network Analyzer is not in general suitable for the investigation of higher frequency transient phenomena such as may occur during switching surges or lightning disturbances. These conditions may be studied by means of a transient analyzer, which is also a circuit analogue of somewhat different construction.

With this, as with the A.C. Network Analyzer, a small scale model of the power system is set up by connecting together various miniature components. In the transient case, however, the model circuit is excited by some suddenly applied voltage, and the transient response is observed on an oscilloscope. The initial disturbance may be produced by a switch or by some form of function generator and it is usually made recurrent for convenience.

The equipment may also be used for the study of steady state conditions involving discontinuities such as rectification or commutation, and also for transient analysis of non-electrical circuits which can be represented by an electrical analogue.

(d) *The Servo-Simulator*: The stability of closed loop control and regulating systems is frequently a factor of the first importance in their design. Analytical methods are available but are complicated (particularly if saturation effects are to be included), and frequently the most satisfactory approach is to construct some form of analogue. Such servo-simulators are made up of elements having the same gains and timelags, to some scale, as the components of the actual system, and connected in a similar way to those of the actual system. A recurrent switch is used for simulating a disturbance, and the response may be observed on an oscilloscope or by means of a pen recorder if lower frequencies are considered.

(e) *The Transformer Analogue Computer*: This is a steady state network analyzer similar in use to the conventional a.c. network analyzer, but differing from it in that in the computer "ideal" voltage transformers are used to represent the impedance of the resistors, inductors and capacitors of the network.

The outstanding features of a computer based on transformer analogue principle are:—

(i) Resistances and reactances are set on the computer as the turns ratios of transformers ;

(ii) The currents of the actual network appear as voltages on the computer ;

(iii) There are four different circuits corresponding to the in-phase and quadrature components of current and voltage ;

(iv) All voltages on the computer are in phase.

Negative impedances can be obtained merely by reversing the transformer connections, and the analyzer is therefore particularly suitable for the solution of equivalent circuits where negative impedances frequently occur.

The computer can be used for: (i) the study of alternating current networks in the steady state ; (ii) the study of behaviour of electrical machines and closed-loop control systems ; (iii) the solution of linear simultaneous equations with complex coefficients ; (iv) the location of the zeroes of polynomials ; and (v) the determination of the latent roots of matrices.

For many problems in engineering the computer has distinct advantages over the conventional form of A.C. Network Analyzer employing variable impedance elements. Negative resistances, resistance-free reactances and current sources can be represented without difficulty by single universal units of the computer, whilst two units (four ideal transformers) suitably coupled together serve to represent mutual inductors, network transformers and other coupling effects, such as phase shifting transformers.

When the computer is in use, there are four separate networks and the *voltages* in these correspond to the in-phase and quadrature components of the voltages and also of the currents in the network under investigation. This feature makes it possible to apply various special restraints which are not possible with a model network, e.g., those required to represent a salient pole synchronous machine by the two-reaction method.

A computer using the transformer analogue for the solution of simultaneous equations was first constructed by Mallock at Cambridge in 1932. The principle of operation of the computer is explained in the following way:

If the equations are of the form:

$$\left.\begin{aligned} a_{11}X_1+a_{12}X_2+a_{13}X_3+a_{14}=0\\ a_{21}X_1+a_{22}X_2+a_{23}X_3+a_{24}=0\\ a_{31}X_1+a_{32}X_2+a_{33}X_3+a_{34}=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

they are first changed into a homogeneous form by choosing a convenient base value x_4 by which all the equations are multiplied, giving:

$$\left.\begin{array}{l} a_{11}x_1+a_{12}x_2+a_{13}x_3+a_{14}x_4=0 \\ a_{21}x_1+a_{22}x_2+a_{23}x_3+a_{24}x_4=0 \\ a_{31}x_1+a_{32}x_2+a_{33}x_3+a_{34}x_4=0 \end{array}\right\} \quad \ldots\ldots \quad (2)$$

where $x_1=X_1x_4$, &c. These equations are represented by four voltage transformers each with four windings, arranged in the manner shown in fig. 1.

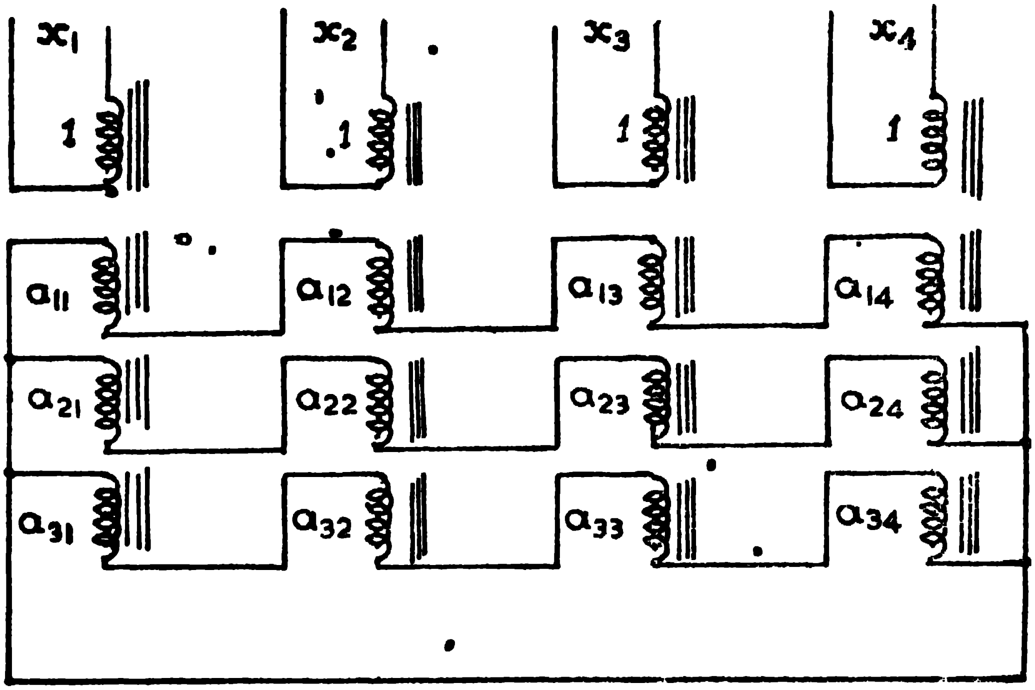

Fig. 1

A voltage v_4 is applied to the x_4 terminals, and the voltages (v_1, v_2 and v_3) across the open terminals are measured. Then

$$\left.\begin{array}{l} X_1=x_1/x_4=v_1/v_4 \\ X_2=x_2/x_4=v_2/v_4 \\ X_3=x_3/x_4=v_3/v_4 \end{array}\right\} \qquad (3)$$

A major advance in the use of the transformer analogue was made by Blackburn in 1937, when he showed that a complex operator such as impedance could be represented by two 3-winding transformers.

Further improvements were made, in the prototype analyzer in operation at the Imperial College (London), by Humphrey-Davies and Slemon. It can be applied to the solution of either impedance networks or sets of linear simultaneous equations with complex coefficients, or to a mixture of both. While there were improvements introduced by Humphrey-Davies and Slemon, the computer was still complicated in conception, operation and maintenance. It was not always apparent that, for any given network, the connections were correct, since they could not be followed as easily as on the direct type of a.c. network analyzer. This was largely because each unit consisted of four terminals for external connections instead of two terminals as in the ordinary network analyzer, thus necessitating special diagrams to translate normal system diagrams to the requirement of connections for the computer. The compensation also was not as good as might be desired, being less than 90% for very low values of voltages at the transformers.

Some further improvements in the design of the computer have been effected at the Indian Institute of Science. By the introduction of special interconnectors, it has now been made possible to utilise, in the large majority of cases, the actual circuit diagram itself for setting up problems on the computer. The interconnections for the series and parallel connections in the modified arrangement are easy to follow. Furthermore, with the double ended units, it is possible to make the analyzer connections on a centralised plugging board and thus reduce the time and labour in solving problems.

By using two non-linear resistors of opposite character, it has been possible to increase the compensation upto 97·5% and maintain it at about the same value over the entire range of voltages.

The computer consists of an assembly of identical universal multiplier units and a measurement unit. Each multiplier unit may represent a complex coefficient, a self or mutual-impedance, a network transformer, a source of current or a source of voltage.

The requirements for each function separately are considered in the following:

(a) *Complex multiplier unit*: If two ideal transformers each having three windings are connected in the manner shown in fig. 2, the voltages across the four pairs of terminals are related by the equations:

$$\left.\begin{aligned} V_{m2} &= n_a V_{m1} + n_b V_{n1} \\ V_{n2} &= n_c V_{m1} + n_d V_{n1} \end{aligned}\right\} \qquad (4)$$

where n_a, n_b, n_c and n_d are the turns ratios of the windings given by $n_a = N_a/N$, &c.

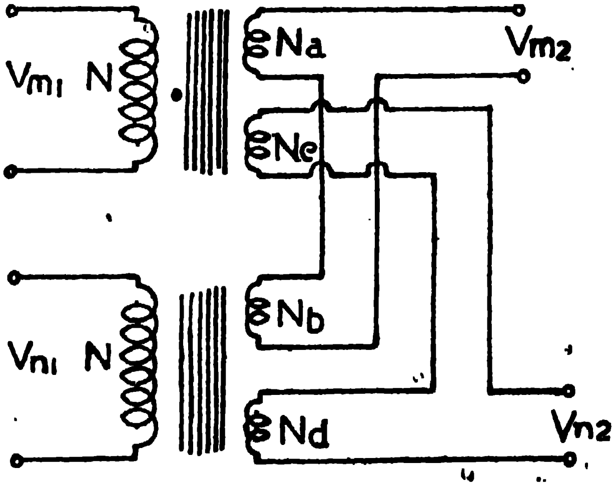

Fig. 2

This arrangement may be used to obtain the solution of a pair of linear simultaneous equations by making the turns ratios equal to the coefficients and letting the two terminal voltages represent the variables.

The vector voltage across an impedance, $Z = R + jX$, in which a current I is flowing is given by

$$V = ZI \qquad (5)$$

This expression may be expanded into two equations giving the in-phase and quadrature components (denoted by suffixes p and q) of voltage and current.

From equation (5)

$$V_p + jV_q = (R + jX)(I_p + jI_q) \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

$$\left.\begin{array}{l} V_p = RI_p - XI_q \\ V_q = XI_p + RI_q \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

A comparison of equations (4) and (7) shows that if $n_a = n_d = R$, $n_b = -X$ and $n_c = X$, the arrangement of fig. 2 may be used to represent an impedance. Thus the relations of equations (7) are satisfied by the arrangement of two ideal transformers as shown in fig. 3.

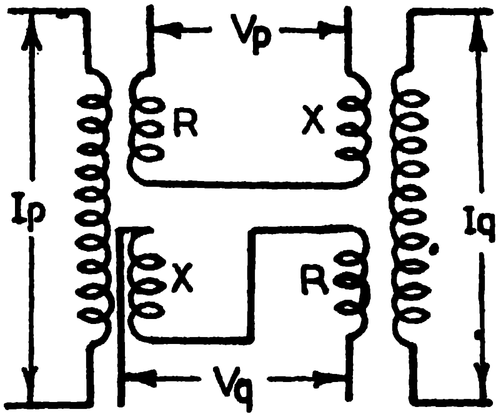

Fig. 3

The current flowing into the impedance Z is simulated by applying voltages proportional to I_p and I_q to the primaries of the two transformers. The resistance and reactance of the impedance are the turn ratios between the secondary and primary of the windings.

The same network may be used to represent an admittance ($Y = G + jB$) if the current and voltage circuits are inter-changed and the tap ratios set as G and B.

(b) *Source unit*: If a voltage V is impressed on an impedance Z, a current I flows through it, where $V = ZI$. To simulate this condition in the transformer analogue it is necessary to impress voltages V_p and V_q (actually in phase) proportional to the in-phase and quadrature components of V, respectively, across the interconnected secondaries of the transformers representing the impedance. Then the voltages measured at the primaries give the currents I_p and I_q in terms of the voltages. In order to provide the two voltages, V_p and V , one three winding transformer is used. The primary is excited by a convenient reference voltage. The tapped secondaries then give two independently adjustable voltages for the in-phase and quadrature phase circuits, which become either voltages sources or current sources according as they are impressed on the voltage or the current circuits, respectively, of the complex unit.

(c) *Representation of Coupling Effects*: To represent coupling effects, such as transformers and mutual impedances, the analogue representation requires special interconnection between four three winding transformers.

The equations for a complex ratio transformer relating the primary and secondary quantities can be written as:

$$\left.\begin{aligned} V_2 &= (a_1+jb_1)V_1, \\ I_1 &= (a_2+jb_2)I_2 \end{aligned}\right\} . \qquad (8)$$

where V_1, I_1 are the primary voltage and current, and V_2, I_2 the secondary voltage and current. The arrangement of four transformers to represent the above are shown in fig. 4 where the voltage ratio is set on the left hand set of two transformers and current ratio on the right hand set.

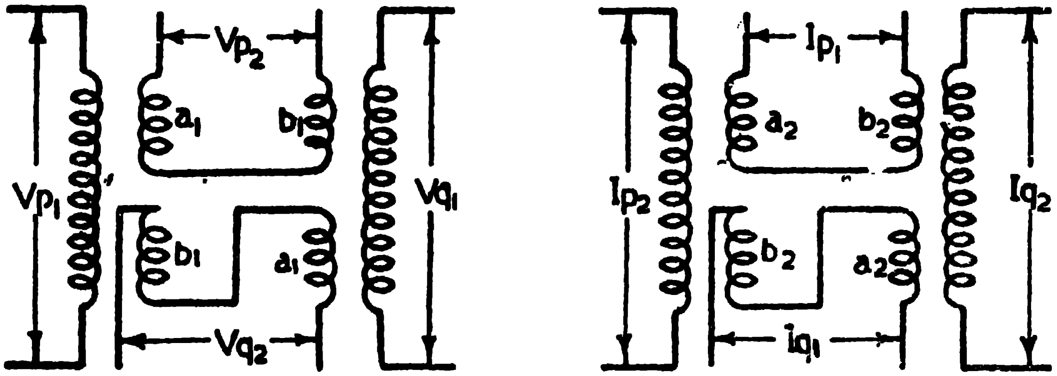

Fig. 4

Similarly, mutual impedances between two separate circuits can be represented by the same arrangement as above, except for the applied voltage and current according to the relations:

$$\left.\begin{aligned} V_2 &= (a_1+jb_1)I_1 \\ V_1 &= (a_2+jb_2)I_2 \end{aligned}\right\} \qquad (9)$$

(d) *The Universal Unit*: This composite unit consists of two sections, each having two three winding transformers, the two secondary windings, called the R and X windings, are suitably tapped in a decade arrangement to enable the range of values to be obtained. The terminals of the tapping switches are brought to a 'sign switch' where the windings can be reversed

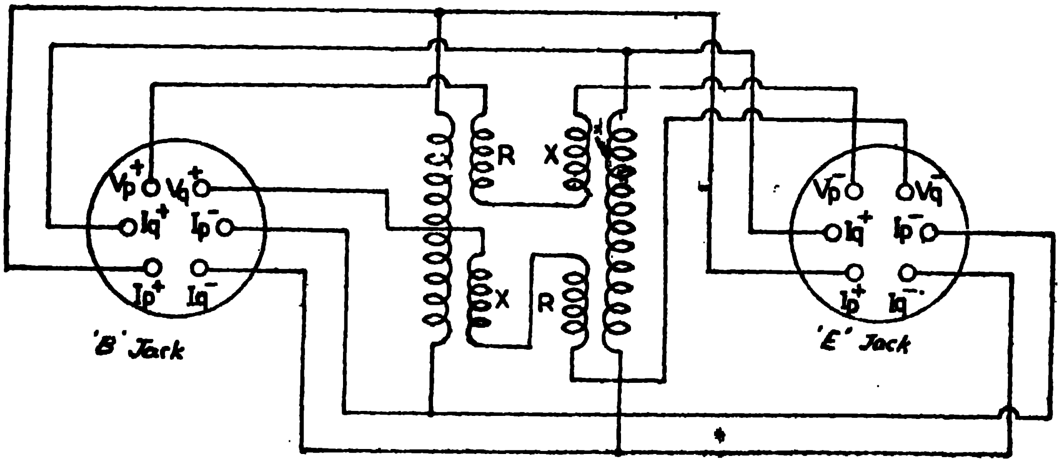

Fig. 5

so that all possible combinations of polarities of R and X may be obtained. The terminals of the sign switch are in turn brought to a 'function switch', the setting of which determines whether a unit is to be operated as an impedance, voltage source or current source.

The terminals of the four circuits of a unit are brought to a plugging board for the purpose of making interconnections between units by means of two six-terminal polarised jacks called the beginning (B) and the end (E) jacks, as shown in fig. 5. It will be noticed that while the B jacks and E jacks have, respectively, the beginning and end leads of the voltage coils, the beginning and end leads of the current coils are connected to both the B and E jacks.

(e) *Network Simulation*: When the units of the computer are interconnected to represent a network, there are four separate circuits formed, the in-phase and quadrature phase circuits of voltage and current. These circuits are electrically separate but are linked by the magnetic flux in the transformers. When the computer transformers representing an element are interconnected to the transformers representing another, the interconnections between the current and voltage circuits in the two units must be such as to satisfy the relationship between the voltage and current in the actual elements. The computer interconnections have also to satisfy the network laws at all nodes and round all meshes.

The interconnections between the units of the computer are made at a plugging board by means of series and parallel interconnectors. Connections at a node point are made by means of parallel interconnectors. In series and parallel connections it must be remembered that while in a series circuit the current remains the same, and the voltage across the different elements add up, in a parallel circuit the voltage remains the same while the currents in the different elements add up. To meet this, the series and parallel interconnectors in the computer are so designed that, for a series connection, the corresponding terminals of the current coils are connected in parallel, whereas the potential coils are put in series. The converse is adapted for the parallel connector.

Similar and suitable provisions are made for connections at one or multiple nodes, for connections for network with cross-over branches, for transformer and mutual coupling connections, etc.

(f) *Compensators*: It has already been mentioned that "ideal" voltage transformers are used in the computer to represent the different parameters of a network. The definition of an "ideal" transformer is that it has no loss of energy, requires no magnetising current and has perfect coupling between windings; the voltage ratio and the reciprocal of the current ratio for any pair of windings would be identical with the turns ratio of the windings, the two voltages and the two currents would be respectively in phase.

The accuracy of a transformer analogue computer depends to a great extent on the accuracy of the individual transformers. The TAC transformers are designed to have the lowest ratio of leakage to mutual reactance by using mumetal cores, in addition further reduction in the ratio is obtained by using auxiliary electronic compensators for supplying the exciting currents of the transformers.

The compensator developed for the TAC is similar in principle to that suggested by Humphrey-Davies and Slemon, but with better compensation over a wider range of voltages.

The transformer, whose exciting current has to be compensated, has an auxiliary winding of the same number of turns as the primary but provided with a centre tap. The terminal voltage of the auxiliary winding is a linear function of the core flux. This voltage, developed across the full winding is applied to a RC phase shifting network controlling a linear cathode-follower. The output voltage of the cathode follower is applied between the ground and centre tap of the compensation winding thereby forcing the exciting current for the transformer through the bottom half of the compensating winding and reducing the current drawn by the primary to a small percentage of its uncompensated value.

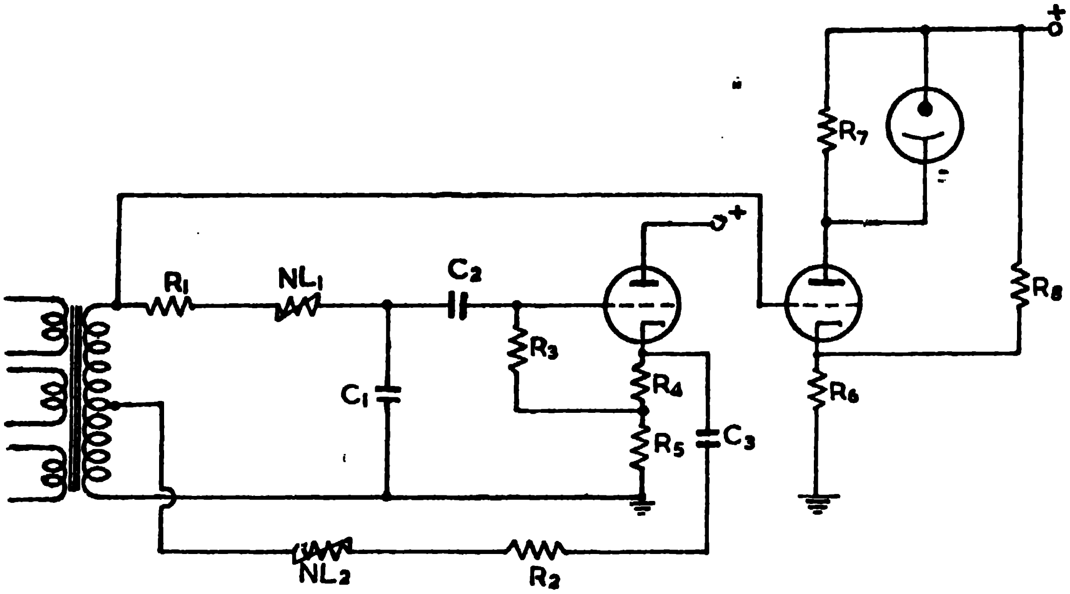

Fig. 6

The improved non-linear compensator not only achieves a compensation of 97·5% at any primary voltage but also maintains about the same high degree of compensation at all voltages over the entire working range. The non-linear compensator circuit with the over-voltage indicator is shown in fig. 6. The two non-linear resistors NL_1 and NL_2 have non-linearities of opposite character.

To avoid possible errors due to over voltages, each transformer is provided with an over voltage detector which lights up a neon lamp on the back panel of the unit when the voltage exceeds 15 mv per turn.

(g) *Measurement*: It has already been indicated that all the variables in any problem are represented in the transformer analogue by their in-phase and quadrature components which appear as voltages in the computer. These voltages should be in phase with each other, and any phase displacement is a useful guide to the magnitude of errors in the solution.

The voltages corresponding to the in-phase and quadrature components may be measured directly by the use of an electronic voltmeter or by the null method for more accurate measurements.

In the null method of measurement the voltage to be measured is compared with the output voltage of a highly accurate and well compensated source unit. The difference voltage is applied to the input terminals of a null detector. When the null detector reads zero, the setting of the source unit gives the required quantity. In order to overcome the effects of any phase angle shift in the computer, provision is made for shifting the phase of the reference voltage through a small angle, keeping the amplitude unaltered. A frequency selective amplifier is interposed before the null detector to suppress the undesirable harmonics that might be present. The null detector used is a vacuum tube voltmeter and the frequency selective amplifier is of the feedback type with a twin T rejector filter network interposed between two cathode followers.

To facilitate rapid measurements, a direct system of measurement of the quantities in polar form and the active and reactive powers is necessary. The direct system of measurement used in the computer is shown in fig. 7.

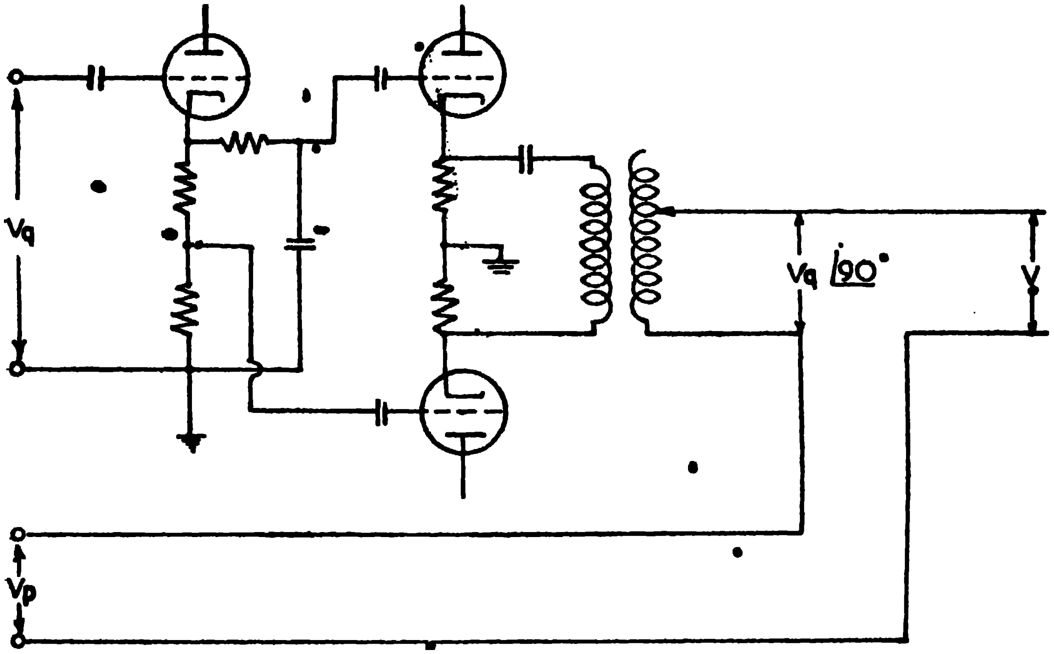

Fig. 7

The quadrature component of voltage is applied to a resistance capacitance network through a linear cathode follower. The voltage between the centre tap of the cathode load resistor and the junction of resistance and capacitance, is applied to the primary of a standard transformer through the interposition of cathode followers. This arrangement avoids earthing of centre tap of the cathode resistance. The output voltage is adjusted to be equal to the input voltage to the cathode follower by means of taps on the secondary of the transformer. The in-phase component voltage is connected in series with the secondary voltage of the transformer and the resultant voltage is measured by a vacuum tube voltmeter. The resistance of the phase shifting network is adjusted for advancing the voltages representing the quadrature components by 90°. The resultant voltage measured, therefore, is the vector addition of convenient values of the in-phase and quadrature components of voltages. The current is also measured in a similar way.

In the use of analogues and other methods in the solution of engineering problems, we have seen that we make use of the equations of the system or the equivalent electric circuit representing the equation. In modern engineering analysis, Kron has shown that a much more basic approach, for all engineering problems, is to obtain the equations for each of the simplest elements of the system (by "tearing apart" as he calls it) and solve for the performance of the system as a whole by introducing the connecting equations between the different elements. In effect the equations are set up in matrix and the solution obtained. The TAC can be easily set up to represent the combination of the equations for the separate elements and of the equations giving the relations between the elementary circuits when connected together. Thus the solution for the complete system is obtained without the necessity of finding equations for the complete system.

In concluding, I must reiterate the need for a change in outlook in our methods in engineering education. There has to be an increased emphasis in the fundamental principles and mathematical tools as well as in the use of these principles in their application to the problems in engineering. Numerous instances can be quoted, where some of the branches of mathematics and physics, considered to be pure and abstract, have been found to be indispensable for research and development in certain fields. Extensive use is made, for example, of Boolean algebra and symbolic logic to the design of switching circuits and computer circuits. The rapid development over the last ten years in the design, as well as in the programming work, of the high speed digital computer has been a result of the closest co-operation between the mathematician and the electrical engineer. Modern design of automatic controls, based on the criterion of minimisation of the mean square error presupposes adequate knowledge of the theory of probability and recent developments in statistics. The development and use of transistors and semiconductors need a good understanding of the theory of solid state physics. Educators in engineering throughout the world are taking a critical look at their respective curricula and directing their efforts to improve the effectiveness of instruction. Without advocating that the policy in our country should be a mere duplication of the changes envisaged in other industrially advanced countries, it should be our aim to modify our engineering education suitably to fit into the pattern of development. Those in charge of our engineering education should profit by the experience of other countries and try to evolve a curriculum which will train the right type of engineers to take part in the national development of our country.

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